Olin Wilmington Technical Series

IV. Geochemical Discrimination Between Groundwater Emanating from the Calcium Sulfate and Woburn Sanitary Landfills

1406

Prepared for:

Olin Corporation
Wilmington, MA Facility

February 10, 1999

geomega

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I. Review of Inductance Logging in Site Monitoring Wells (9/15/98)

II. A Statistical Analysis of Water Quality Trends in the Meadows Brook Aquifer and Proposed Modifications to the Western Bedrock Sentinel Well Program (9/29/98)

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Executive Summary

The Massachusetts Department of Environmental Protection (MADEP) is concerned that leachate from the Calcium-Sulfate Landfill (CSL) may be migrating offsite and potentially impacting private wells along Border Avenue, and overburden wells as far west as GW-75D. However, interpreting the provenance of solutes in area groundwater is complicated by the presence of the ~40 acre Woburn Sanitary Landfill (WSL) immediately south of, and adjacent to, the 2.5 acre CSL. This report evaluates CSL/WSL impacts and assesses local groundwater background chemistry.

Groundwater flow in the area is influenced by local bedrock highs and by east-west trending paleochannels incised in bedrock away from the CSL. There is a quasi-radial mound underlying the WSL and flow toward the southwest (constrained by bedrock topography) under the CSL. The disposal histories of both landfills are different resulting in distinct leachate chemistry, with the CSL having a predominantly calcium- sulfate character, while the WSL leachate is characterized by elevated alkalinity.

The groundwater associated with each facility has unique characteristics that plot in separate geochemical space on both Piper and quaternary diagrams. The CSL plume is limited to an area immediately adjacent to the CSL, only extending as far as GW-40D. In contrast, the WSL has influenced groundwater chemistry at least as far downgradient as GW-75D, and co-mingles with CSL groundwater in an area around the GW-40D well. Based on a comparison of groundwater chemistry between the residential bedrock wells and GW-81BR, and the trilinear diagrams, there is no evidence of impacts on bedrock wells from the CSL (Table 2).

In the local residential wells the presence of manganese (0.059 mg/l) and sodium (47 mg/l) is entirely consistent with the regional background chemistry (USGS 1992). There are no apparent impacts from the CSL, nevertheless, Olin will continue to monitor the residential well chemistry as requested by MADEP, and continue to provide these data to the homeowners.

1.0 Introduction

The Massachusetts Department of Environmental Protection (MADEP) received and reviewed a report entitled *"Report of Groundwater Sampling and Analysis in the Vicinity of the Calcium Sulfate Landfill"* prepared by Law Environmental Consultants, Inc. (LAW 1998). MADEP provided comments on the conclusions of the report (Letter from C. Pyott to Olin Corporation, November 9, 1998). The gist of the comments was that leachate from the Calcium-Sulfate Landfill (CSL) was potentially migrating beyond the revised Disposal Site Boundary identified by LAW (1998) and potentially impacting the Baker, Lessard, Popa and Sullivan private wells along Border Avenue. Concerns were also raised relating to the potential for migration of solutes from the CSL to GW-75D.

In response to MADEP comments, Olin obtained additional data, and further evaluated the data submitted to MADEP. Accordingly, additional insights as to the fate and transport of solutes from the CSL can now be provided. The additional analysis demonstrates that the adjacent Woburn Sanitary Landfill (WSL) is the source of the solutes observed in GW-75D, and that neither the CSL nor the WSL has impacted the private wells along Border Avenue. The site boundary surrounding the CSL has been confirmed and supported by additional analyses.

This subsequent evaluation builds upon the analysis presented by LAW (1998), hence the reader is referred to that document for information pertaining to sampling protocols, well completion information, and the underlying chemical data (provided here in Table 1). Other data from LAW (1998) are replicated in this document only where their inclusion directly assists in understanding the fate and transport of solutes from the landfills.

2.0 The History of the Calcium-Sulfate and Woburn Sanitary Landfills

Both the WSL and the CSL lie within the confines of the Mystic watershed basin, and as such are physically distinct from the Ipswich basin. There is no DAPL or DAPL-related diffuse layer associated with either the CSL or the WSL (Geomega 1999). The location and relative size of the landfills are shown in Figure 1.

2.1 The Calcium-Sulfate Landfill

The CSL location and plans were approved by the Massachusetts Department of Public Health on January 16, 1974, and by the Town of Wilmington Board of Health on October 11, 1974. The CSL operated from 1975 until 1987 when the facility was capped, topsoiled, and seeded with final closure status requested in 1988.

The landfill was operated as a mono-fill throughout its operational history. The chemistry of the fill material (Appendix A) is essentially pure gypsum ($CaSO_4 \cdot 2H_2O$) in the form of a relatively fine-grained sediment. A cross-section through the CSL (Figure 2) shows the historical topographic evolution of the landfill surface. The pre-emplacement topography was digitized from a 1971 as-built of the WSL and vicinity (Perkins 1971), and the post-emplacement surface grade, the screen depths of wells SL-2 and SL-5, and the presumed pre-fill grade (dashed line on Figure 2) from Olin (1997). The surface area of the CSL is approximately 2.5 acres with an approximate volume of 37,000 cubic yards. Although there may be minor variations in the permeability and porosity of the CSL fill, it is likely to exhibit a consistent range relative to the WSL.

2.2 The Woburn Sanitary Landfill

The WSL began operations in 1966 at the site of an old gravel pit receiving commercial, industrial, and household wastes until 1986. The overall surface area utilized for landfill operations was approximately 40 acres; almost sixteen times the size of the CSL. The Maguire Group, Inc. submitted an initial closure plan in July 1989, although to date, closure activities have not been completed.

Leachate seeps have been identified leaving the WSL along the southwest face, resulting in ponding of water on the southwest side of the site near the railroad beds and MW-5 (Figure 1). Woburn Truck Parts, located adjacent to these seeps, has retained legal counsel to redress flooding-related property damage related both to these seeps and to enhanced localized groundwater flow due to the WSL (Davis 1988). Furthermore, past monitoring of the MG-2 well cluster in the south of the WSL (Figure 1) has demonstrated significant bedrock contamination, and has indicated a potential downward component to the flow of local groundwater (MADEP 1990).

3.0 Geochemical Processes in Landfills

The geochemistry of the CSL and WSL represents a stark contrast in the level of complexity due to the presence of organic wastes in the WSL that are absent in the CSL. In addition, the CSL is a mono-fill (one material disposed) while the WSL is a hetero-fill with multiple waste types and sources, resulting in interdigitating layers of different materials, including potential daily clay/soil cover.

Disposal of liquid and solid wastes in sanitary landfills creates an environment where the presence of organic constituents disposed in trash degrade, mediating shifts in inorganic chemistry. For example, the presence of carbon compounds, e.g., petrochemical, wood, plants, paper, etc. (generically characterized as CH_2O), consume available oxygen during bacterial respiration (Figure 2), generating carbon dioxide and water, i.e.;

$$CH_2O + O_2 \Leftrightarrow CO_{2(g)} + H_2O \qquad \text{(Eq. 1)}$$

Subsequently $CO_{2(g)}$ complexes with water to form carbonic acid and additional bicarbonate alkalinity, i.e.;

$$CO_{2(g)} + H_2O \Leftrightarrow H_2CO_3 \Leftrightarrow H^+ + HCO_3^- \qquad \text{(Eq. 2)}$$

In addition, reducing conditions in the landfill facilitate reduction of nitrate (originating from organic-N in refuse) to nitrite, i.e.;

$$R\text{-}NO_3^- + CH_2O \Leftrightarrow R + H_{2(g)} + NO_2^- + CO_{2(g)} \qquad \text{(Eq. 3)}$$

where R represents an organic group, while nitrite is biologically reduced to ammonia, i.e.;

$$NO_2^- + 2CH_2O \Leftrightarrow 2CO_2 + NH_4^+ + 2e^- \quad \text{(Eq. 4)}$$

resulting in ammonia generation in the WSL. Hydrogen gas and organic acids are rapidly utilized in methanogenic reactions that generate methane, i.e.,

$$CH_3COOH \Leftrightarrow CH_{4(g)} + CO_{2(g)} \quad \text{(Eq. 5)}$$

and:

$$CO_2 + 4H_2 \Leftrightarrow CH_{4(g)} + 2H_2O \quad \text{(Eq. 6)}$$

Under the reducing conditions adjacent to the landfill, sulfate can be reduced to sulfide, i.e.;

$$SO_4^{-2} + 9H^+ + 8e^- \Leftrightarrow HS^- + 4H_2O \quad \text{(Eq. 7)}$$

with the reducing environment solubilizing iron and manganese (Table 2) present in naturally-occurring iron and manganese-bearing minerals (e.g., amphiboles and/or pyroxenes). The reaction mechanisms controlling inorganic geochemistry in a typical municipal landfill are complex (Baedecker and Back 1979, Senior 1990, Hackley et al. 1996), with transport characteristics dependent on the redox characteristics of the solutes (Davis et al. 1994) and receiving waters (Figure 3).

In contrast, the CSL represents a mono-fill in which organic constituents characteristic of municipal sanitary landfill leachates (Reinhard et al. 1984) are conspicuously absent. Consequently, the reactions typical of a sanitary landfill that generate methane, ammonia, and that mobilize iron and manganese are insignificant due to the absence of organic material. Thus reactions governing solute transport from the CSL will be driven more by simple dissolution/sorption/precipitation reactions relating to gypsum ($CaSO_4 \cdot 2H_2O$), rather than by organically controlled redox reactions (e.g., Eq. 4, 6 and 7) as is the case for the WSL (Figure 3).

The substantive reaction controlling gypsum solubility in the CSL is:

$$CaSO_4 \cdot H_2O \Leftrightarrow Ca^{+2} + SO_4^{-2} + H_2O \qquad \text{(Eq. 8)}$$

It is possible that despite neutralization in the holding ponds (that resulted in the precipitation of the gypsum sludge that was eventually deposited in the CSL), that there is some remnant ammonia. Based on a description of the bulk chemistry of the CSL, the primary components were water, gypsum and calcite with traces of chloride, sodium and ammonia-based compounds (Appendix A).

Wells SL-5 and SL-6 constitute the archetypal CSL groundwater chemistry due to their location on the preferential groundwater flow path from the CSL, as controlled by bedrock outcrops. Additionally, due to surrounding bedrock outcrops (Figure 4) they have not been impacted by the WSL groundwater mound. MG-2A is sited within the confines of refuse disposal in the WSL (Figure 1) and as such is representative of WSL groundwater conditions. In contrast to the WSL, sulfate in the CSL will not be reduced to sulfide (Eq. 7) because the reductive driving forces provided by organic carbon are absent. As a corollary, iron and manganese concentrations in the archetypal CSL well (SL-5) are much lower than in the characteristic WSL well (MG-2A) due to the less reducing environment present under the CSL.

4.0 Evaluation of Bedrock Elevations in the CSL/WSL Area

The available top-of-rock data (Figure 4) indicate a buried channel running along the western borders of the CSL and the WSL landfills, and a large bedrock outcrop area in the vicinity of which are several residential wells (Figure 4). Deeper areas in the channel are defined by wells GW-40D and GW-75D. There is also a potential bedrock feature beneath the WSL that may orient groundwater flow from the WSL to the west along the buried channel towards GW-75D.

4.1 Implications of Bedrock Elevations in the CSL/WSL Area

The elevated surface of the Calcium Sulfate Landfill is due, in part, to a bedrock high beneath the landfill. The presence of a bedrock high and outcrops in the vicinity of the CSL also influence the groundwater flow pathways. For example, the CSL was emplaced to the south of a bedrock outcrop that acts as a groundwater divide (Figure 4), funneling flow to the northeast and to the southwest. Another bedrock high southeast of the CSL precludes groundwater migration in that direction, as evidenced by the fact that well SL-4 was dry when sampled in April 1998. An area of bedrock outcropping west of the CSL and north of the Sullivan well (Figure 4) is part of the groundwater divide that extends into the CSL, causing groundwater to flow to the south in the area between GW-40 and Border Avenue. The bedrock outcrops also result in locally high amounts of recharge to the groundwater flow system in the spring due to precipitation runoff.

4.1.1 Runoff South of the CSL

Bedrock outcrops are a dominant feature, particularly to the west and southeast of the CSL (Figure 4), contributing substantial clean water recharge to the area *via* precipitation runoff. Recharge, in turn, may be a significant factor controlling downgradient groundwater solute concentrations. For example SL-1D, SL-2, and SL-3 in the CSL area probably receive considerable runoff from exposed outcrops located to the west and northwest. Although GW-40D is located in close proximity to these wells, the observed solute concentrations in that well are considerably higher. However, GW-40D is screened much deeper (41-51 feet NGVD) than SL-1D, SL-2, and SL-3 (70-80, 69-79, and 70-80 feet NGVD, respectively), suggesting that the recharge/mixing effect is limited to shallower depths (i.e., shallow groundwater has lower constituent concentrations due to recharge dilution, whereas concentrations are higher at depth due to limited dilution).

4.1.2 Runoff North of the CSL

The runoff effect is also apparent in the solute concentrations in wells SL-5, SL-6, and GW-20. SL-5 and SL-6 have the highest CSL-related solute concentrations, whereas GW-20 has very low concentrations. SL-5 and SL-6 are located in a channel between two bedrock exposures immediately northeast of the CSL, while GW-20 is located a short distance (200 feet) away in an apparent bedrock valley. As previously mentioned, there is preferential groundwater flow to the northeast (i.e., to SL-5 and SL-6) and to the southwest due to a topographic high in the southeast part of the CSL and to a bedrock outcrop to the southeast (Figure 4). Hence, the bedrock channel may serve to direct flow of high concentration groundwater from the CSL through SL-5 and SL-6, where it is subsequently diluted by recharge prior to reaching GW-20.

5.0 Groundwater Flow in the CSL/WSL Area

The elevated topographic and bedrock surfaces in the vicinity of the CSL cause groundwater to flow from the CSL toward the southwest; whereas groundwater flow is radial away from the WSL. However, due to the expected lower permeability material and thin saturated thickness of the CSL, the volume of flow per unit area through the CSL is likely to be less than in the WSL. In the WSL the greater relief and the lower bedrock surface results in a much larger saturated thickness, that in combination with the more permeable material, results in a greater volume of groundwater flow through the WSL. Additionally, groundwater mounding beneath the WSL, which is indicated by data from monitoring wells along the southern edge of the landfill (Figure 1), is consistent with similar mounding conditions reported at other municipal landfills with elevated surface topography.

Groundwater flow in the CSL/WSL area is controlled predominantly by the bedrock surface and by elevated groundwater surface especially under the WSL. Groundwater beneath the landfills coalesces along a common boundary between SL-3 and GW-40D, with the WSL mound approximately 15 times the area of the CSL. In the vicinity of wells AN-1 and AN-2, westerly groundwater flow from the WSL converges with southerly flow from the groundwater divide extending through the CSL, and the direction of groundwater flow changes to the southwest, generally following the axis of the bedrock trough from GW-40 to GW-75 (Figure 4). The northern extent of the WSL mound co-mingles with the CSL flow in the vicinity of GW-40D, while based on groundwater chemistry, the western extent of flow from the WSL extends to GW-75D. Hence GW-40D and GW-75D appear to be the recipients of some contribution from the WSL. Additionally, leachate seepage from the WSL has caused localized flooding conditions around MW-5 (Section 2).

6.0 Review of Background Groundwater Chemistry

Chemical concentrations in samples from the Baker, Lessard, Popa, and Sullivan residential wells in the vicinity of the CSL and WSL were included in the background data presented in the Supplemental Phase II Assessment (Olin 1997). These data are highly variable, routinely exceeding the sodium MCL (Figure 5) and manganese SMCL (Figure 6). In addition, historic high concentrations in some wells have not been confirmed by subsequent analyses, demonstrating that the CSL could not be consistently influencing domestic well chemistry.

All values are within the range of concentrations observed in other public supply wells in the Mystic Basin (USGS, 1992). For example, the average naturally occurring manganese concentration in the Mystic Water-Resources Planning Basin area is 0.18 mg/l while this Basin has the highest naturally-occurring median sodium concentration (35 mg/l) in Massachusetts (USGS 1992, Appendix 1). Hence, the naturally elevated occurrence of these constituents in these residential wells is consistent with the basin-wide drinking water condition, rather than indicative of CSL-related contamination.

Finally, the time-dependent water chemistry in domestic wells closest to the GW-40D/GW-75D trough (Appendix B) demonstrates decreasing sodium concentrations in the Lessard well from 33 to 9 mg/l between 1996 and 1998. Similarly, manganese and sodium in the Popa well decreased between 1996 and 1998 (from 0.075 to 0.059, and from 31 to 15 mg/l, respectively). If there were a CSL-facilitated impact, it would be more reasonable to expect sodium and manganese concentrations to have either remained constant or to have increased over that period. Hence these minor temporal variations may be ascribed to natural random fluctuations in groundwater chemistry.

7.0 Area Groundwater Chemistry

The extent of the influence of the landfills on local groundwater was assessed using the data set collected in 1998, together with groundwater data from other background wells in the area collected during the Phase II investigation. Temporal solute variability is minimal in the background wells, allowing use of these data in this analysis.

Based on the conceptual paradigm describing landfill geochemistry (Section 2), selected parameters were plotted to determine which compounds could discriminate between the

CSL and WSL water types. Effective forensic geochemical indicators should, 1) be generally non-reactive in the subsurface, 2) have been analyzed across the entire area, 3) exceed local background concentrations, and 4) occur at high enough concentrations to allow unambiguous source discrimination.

Based on the conceptual paradigm for solute generation and transport from the CSL and WSL (Section 2), calcium and sulfate provide the best discriminatory power from the CSL (Figure 7). SL-5, SL-6 and GW-40D, all in the immediate vicinity of the CSL contained 418 mg/l, 418 mg/l, and 340 mg/l of calcium compared to a local background of 32 mg/l (Table 2). Sulfate in these wells was 1190 mg/l, 1070 mg/l and 1060 mg/l, respectively, compared to a local background of 24 mg/l (Table 2).

Bicarbonate alkalinity is a viable discriminatory parameter for WSL contributions (Figure 8). In the deep wells (MW-3, MW-8D and MG-2A) around or within the confines of the WSL (pH 6.5-6.8), bicarbonate alkalinity averaged 340 mg/l compared to ~50 mg/l in CSL wells SL-5 and SL-6 (pH 6 and 5.7 respectively). The presence of 188 mg/l alkalinity in GW-40D at first appears anomalous until it is recognized that it is consistent with the level in MW-3, MW-8D, and MG-2A. These data demonstrate that the WSL groundwater mound actually encroaches onto the Olin property, hence explaining why alkalinity is higher in this well than in SL-5 and SL-6 (Figure 8).

Other parameters by themselves were 1) either consistently below the method detection limit (e.g., chromium), 2) reactive in the subsurface (e.g., iron, manganese), 3) at similar concentrations in both the CSL and WSL areas (e.g., magnesium and sodium), 4) ambiguous (e.g., ammonia and potassium), or 5) consistent with local background (e.g., pH in the residential wells).

8.0 Forensic Geochemistry

There are several methods that can be used to discriminate between the CSL and WSL plumes, including 1) ion ratios, 2) trilinear diagrams, and 3) three-dimensional quaternary plots. These interpretations were combined with knowledge of the bedrock surface, groundwater hydrology (mounds and flow directions), the conceptual landfill paradigms, and the bulk groundwater chemical analyses to interpret the data. The results are described in detail in the ensuing sections.

8.1 Ion Ratios

The CSL mono-fill was comprised (Appendix A) almost exclusively of water and gypsum (calcium sulfate). In theory, a calcium sulfate groundwater signature requires a 0.4:1.0 calcium:sulfate ratio based on the stoichiometry of gypsum. Hence plotting this ratio downgradient from the two landfills provides insight as to the distal extent of the CSL plume (Figure 9). While sulfate is generally non-reactive in the subsurface, calcite solubility, and hence calcium concentrations may be controlled by the pH. However calcium concentrations outside the CSL are consistent.

In the vicinity of the CSL, calcium:sulfate ratios approximate 0.4 (Figure 7) with calcium and sulfate concentrations dissipating at MW-5 (Figure 5). Indeed, based on a combination of ion ratios and bulk chemistry the wells clearly impacted by the CSL are restricted to SL5, SL6 and GW-40D.

Hence the CSL plume is constrained to an area in the immediate vicinity of the CSL. Further, the sulfate:calcium ratios in GW-75D are consistent with those in the WSL ($Ca:SO_4>0.4$) rather than in the CSL ($Ca:SO_4\sim0.4$) (Figure 9). Reactive transport of calcium does not explain the reduction in these ratios between GW-40D and GW-75D because any precipitation or sorption of calcium along the flowpath should result in increasing, not decreasing sulfate:calcium ratios. Neither can this difference in ratios be explained by dissolution of formation calcite, i.e.:

$$CaCO_3 + H^+ \Leftrightarrow Ca^{+2} + HCO_3^- \qquad \text{(Eq. 7)}$$

because the pH along a hypothetical trajectory between GW-40D to GW-75D decreased by only 0.6 units from 7.4 to 6.8. Based on PHREEQC (USGS 1995) calculations this shift has no effect on the groundwater alkalinity or calcium concentrations (Appendix C) even if calcite is assumed to dissolve to equilibrium at pH 7.4.

The ratios of sulfate (from the CSL) and alkalinity (from the WSL) represent another potentially useful ion pair. The sulfate:alkalinity ratio characteristic of the CSL groundwater is 5.6-24 (Figure 9), but only 0.1-0.3 in the WSL groundwater. In GW-75D the sulfate alkalinity ratio is 0.2, indicating that this groundwater is chemically more similar to the WSL than the CSL. The average ratio for the residential wells (i.e. background) is 0.8.

8.2 Trilinear Diagrams

The relative proportions of cations and anions in wells in and around the CSL and WSL were plotted on a trilinear (Piper) diagram to determine if trends exist that allow discrimination between the different water types. This technique, in conjunction with knowledge of the bedrock contours, the groundwater flow directions, and absolute solute concentrations allows differentiation between three distinct populations; a CSL group, a WSL group, and the remaining background group, which includes the residential wells and the unimpacted monitoring wells (Figure 10).

On the trilinear diagram the major discriminant between the CSL- and WSL-related groundwaters is the level of sulfate and alkalinity, respectively, both of which are non-reactive in the Mystic Basin groundwater environment. Consequently, the CSL wells (SL-1 through SL-3, SL-5 and SL-6) plot as calcium sulfate waters (Figure 10, area I) while the deep wells to the south of the WSL (MG-2A, MW-3 and MW-8D) plot as a calcium chloride-bicarbonate type (Figure 10, area II). GW-75D plots close to the calcium chloride-bicarbonate waters, while GW-40D plots in the vicinity of the calcium sulfate population, indicating that these wells are chemically most similar to the WSL and CSL, respectively. Shallow WSL well MG-2C plots on the calcium bicarbonate area of the trilinear diagram due primarily to the elevated alkalinity (1280 mg/l) in this well.

The residential and bedrock monitoring wells are chemically distinct from both the CSL (Area I) and the WSL (Area II), indicating that they represent local background in the bedrock intervals in which they are screened, and are not affected by either CSL- or WSL-related waters. Indeed, the completion depths alone of the domestic wells (i.e., ~450 feet bgs for the Sullivan well, and ~700 feet bgs for the Lessard well) argues against impacts from these sources because the bedrock water quality in the shallower bedrock wells GW-81BR that is adjacent to the CSL does not appear to have been impacted (Section 8.5).

Wells SL-1D and SL-2 represent special cases in that they plot in the CSL domain, yet the calcium and sulfate concentrations are more consistent with background levels (Figure 7). Exploding the Piper diagram to a quartenary incorporating the total dissolved solids concentration in the CSL wells on the vertical axis highlights this difference (Figure 11).

8.3 Quarternary Plot

A 3- dimensional plot was prepared using alkalinity, calcium, and sulfate concentrations normalized to total dissolved solids (TDS). This construct was used to further test the hypothesis that the residential wells are not affected by CSL leachate, and to evaluate the relationship between CSL wells SL-1D and SL-2 with the archetypal CSL wells SL-5 and SL-6. This plot demonstrates that end-member signatures of the CSL wells (SL-5 and SL-6; high calcium sulfate with high TDS) and WSL wells (MG-2-A; high alkalinity and high TDS) are unique and divergent (Figure 11). SL-3 plots at an intermediate chemical condition (note the relative length of the join on Figure 11) between the SL-5, SL-6 and GW-40D cluster and the SL-1D and SL-2 pair. The association between GW-40D with the CSL, and GW-75D with the WSL is also clear.

The residential wells also cluster together (Area C) indicating a lack of impact from the CSL landfill (Area B). The CSL wells SL-1D, SL-2 and SL-3 fall near the background group (Area C) demonstrating a greater similarity with background, rather than landfill conditions. Wells near the WSL (GW-75D, MG-2A and others) fall as expected, in the WSL landfill group (Area A).

8.4 Fractured Bedrock Pathway in GW-81D

The four residential wells completed in the bedrock provide a representative background population against which the GW-81D and GW-81BR well chemistry can be compared (Table 2). In the residential wells, alkalinity, ammonia (at the detection limit), and calcium are virtually identical to the GW-81 cluster. Chloride concentrations are slightly higher, while sulfate levels are slightly lower in the residential wells as compared to the GW-81 cluster. Neither GW-81D nor GW-81BR plot within the influence of the CSL (Figures 10 and 11), hence bedrock well GW-81BR appears to be unimpacted by the CSL.

8.5 Extent of Plume Migration

The data presented in this report demonstrate that the CSL plume is local and essentially restricted to the Olin property. The CSL plume extent is constrained to the east by monitoring well GW-20, to the southwest by SL-2, and to the west by GW-81D. In contrast, the WSL plume extends as least as far as GW-75D to the west and to an undefined distance to the south (e.g., Figure 8). Figure 12 shows the resulting CSL site boundary based on these constraints.

9.0 Conclusions

1) The disposal histories of the CSL (mono-fill) and the WSL (hetero-fill) are entirely different, which results in profound differences in the respective leachate chemistries (Section 3).

2) While the WSL and CSL have a common groundwater mound boundary from SL-3 to GW-40D, the WSL has a substantially larger mound than the CSL (Figure 1). The northern extent of the WSL plume encroaches onto the Olin Property in the vicinity of SL-3 and GW-40D, while the western extent of the plume approaches GW-75D (Figure 8).

3) Groundwater chemistry follows predictable patterns based on knowledge of disposal histories (Section 2), groundwater flow directions (Figure 1) and landfill geochemistry (Figure 3).

4) Based on a comparison of groundwater chemistry between the residential bedrock wells and GW-81BR, and the trilinear diagrams (Section 8.2), there is no evidence of impacts on GW-81BR by the CSL (Table 2).

5) The CSL plume is limited to an area immediately adjacent to the CSL, only extending as far as GW-40D (Figures 7 and 9). The CSL does not appear to have impacted GW-75D because the GW-75D water chemistry is substantially different from the CSL. In contrast, the WSL has influenced groundwater chemistry at least as far downgradient as GW-75D and co-mingles with CSL groundwater at the GW-40D well (Figure 8).

6) There are multiple lines of evidence that the CSL has not impacted either GW-75D or the residential wells (e.g., Figures 10 and 11). The presence of manganese at 0.059 mg/l is consistent with regional background chemistry (USGS 1992), while sodium (47 mg/l) is consistent with the regional background for this solute (Table 2). Nevertheless, Olin will continue to monitor the residential well chemistry through the end of the Phase II Comprehensive Site Assessment as requested by MADEP, and continue to provide these data to the homeowners. In addition, chemical trends will be subject to the same analysis as proposed for the Western Bedrock Valley Sentinel Well Program (Geomega 1998) to test for changes in groundwater quality. Those interpretations will also be provided on an annual basis to the homeowners .

7). The Disposal Site Boundary has been redrawn to include GW-40D (Figure 12) which has clearly been impacted by the CSL. The Olin Disposal Site Boundary does not extend to GW-75D.

10.0 References

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Tables

Table 1. Results Summary of Analytical (Metals and Inorganics) Parameters (Modified from LAW 1998)

Well ID		AN-1	AN-2	Baker	Lessard	Popa	Sullivan	MG-2A	MG-2C	MW-3	MW-3[1]	MW-5	MW-8D
Location		Anchor Autobody		Private Property Water Wells				Woburn Landfill					
Screened Intervals		NDA	NDA					47.5 - 44.5	69.5 - 64.5	85.9 - 71.4	85.9-71.4	84.9 - 71.1	58.4 - 53.6
Depth to Bedrock		60.0[a]	60.0[a]					37.8	37.8	73.0[b]		46.0	51.8[a]
Screened Horizon		Shallow		Bedrock				Deep	Shallow	Deep	Deep	Shallow	Deep
Sample Date		4/24/98	4/24/98	4/24/98	4/23/98	4/23/98	4/23/98	4/24/98	4/24/98	4/29/98	4/29/98	4/29/98	4/29/98
Inorganics	Units												
Bicarbonate Alkalinity as $CaCO_3$	mg/L	ND	10.0	8.0	94.0	106	34.0	1280	336	388	394	14.0	290
Carbonate Alkalinity as $CaCO_3$	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chloride	mg/L	ND	60	75.5	45.7	21.3	59.6	110	6.38	46.0	38.0	4.3	42.0
pH (field)	pH units	7.20	8.80	7.43	7.52	7.24	6.78	6.66	7.40	6.51	6.51	6.27	6.76
pH (lab)	pH units	5.45	5.50	5.68	7.59	7.69	6.30	6.70	6.52	5.96	6.01	5.36	6.31
Sulfate ion	mg/L	4.6	27.1	16.4	31.8	26.3	22.2	14.3	99.9	36.2	63	36.0	40
Specific Conductance (field)	uS/cm	395	148	350	394	334	346	2539	862	969	969	159	951
Specific Conductance (lab)	uS/cm	446	152	361	418	331	354	2990	824	986	977	162	866
Total Dissolved Solids	mg/L	84	159	253	265	148	80	979	520	531	574	176	498
Ammonia -N	mg/L	1.72	ND	ND	0.88	ND	0.66	158	5.72	30.6	27.5	ND	25.8
Temperature (field)	°C	9.0	8.3	9.7	11.3	11.9	11.6	12.0	8.4	9.6	9.6	7.9	9.4
Metals													
Calcium	mg/L	3.45	12.5	11.1	54.5	38.8	22.4	120	132	49.0	49.5	13.5	68.2
Chromium	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Iron	mg/L	0.047	0.112	0.037	0.038	ND	0.052	23.3	14.7	ND	ND	ND	0.425
Magnesium	mg/L	0.28	1.09	1.21	4.90	5.26	1.97	42.3	9.13	25.6	26.1	1.12	12.2
Manganese	mg/L	ND	0.186	ND	ND	0.059	ND	2.14	0.584	1.87	1.90	0.021	5.01
Potassium	mg/L	1.6	ND	1.6	1.6	1.3	2.6	55.7	8.0	26.6	26.7	1.6	10.6
Sodium	mg/L	1.80	13.2	46.7	9.30	15.1	36.6	117	10.5	60.4	51	12.6	49.5
SO_4 : Ca	mg/L	1.3	2.2	1.5	0.6	0.7	1.0	0.1	0.8	0.7	1.1	2.7	0.6
SO_4 : Alk	mg/L		2.7	2.1	0.3	0.25	0.7	0.01	0.3	0.1	0.1	2.6	0.1

Well ID	GW-20[4]	GW-40D	GW-46D	GW-75D	GW-81BR	GW-81D	SL-1D	SL-2	SL-3	SL-5	SL-6	SL-6[2]	SL-7[3,4]	SL-8[4]	Method PCLs
Location	Olin Site Wells						Olin Calcium Sulfate Landfill Wells								
Screened Intervals	73.8-68.8	51.4 - 41.4	76.2 - 66.2	45.4 - 35.4	65.2 - 36.2	81.1 - 71.1	79.7 - 69.7	78.5 - 68.5	79.5 - 69.5	87.6 - 77.6	79.1 - 69.1	79.1 - 69.1	88.3 - 83.3	89.9 - 84.9	
Depth to Bedrock	68.5	46.4	70.2	40.4	72.6	72.6	71.7	70.5	71.5	79.6	71.1	71.1	86.3	87.9	
Screened Horizon	Deep	Deep	Deep	Deep	Bedrock	Deep	Deep	Deep	Deep	Deep	Deep	Deep	Deep	Deep	
Sample Date	7/9/98	4/23/98	4/22/98	4/22/98	7/17/98	7/17/98	4/22/98	4/22/98	4/22/98	4/22/98	4/22/98	4/22/98[2]	4/23/98	4/23/98	
Inorganics															
Bicarbonate Alkalinity as $CaCO_3$	66	188	44.0	298	72	50	10.0	ND	26.0	88.0	56.0	58.0	NA	NA	5.0
Carbonate Alkalinity as $CaCO_3$	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	5.0
Chloride	5.1	117	29.8	104	46.2	28.6	14.9	1.06	3.19	23.4	27.6	26.6	NA	NA	1.0
pH (field)	6.68	7.42	6.13	6.82	7.04	6.65	5.77	6.02	5.35	5.88	5.41	5.41	5.44	5.93	-
pH (lab)	6.30	7.42	6.07	6.76	7.91	6.70	5.36	5.30	5.37	6.01	5.70	5.56	NA	NA	-
Sulfate ion	32.7	1061	26.8	52.3	61.3	36.5	109	37.6	140	1190	1070	1370	10.4[3]	40.3	0.1
Specific Conductance (field)	155	2745	221	1060	342	251	257	131	680	2062	2351	2351	74	183	-
Specific Conductance (lab)	196	3080	241	1090	425	285	273	147	775	2490	266	3140	NA	NA	15
Total Dissolved Solids	120.5	1950	ND	478	261	160	194		408	1700	1950	2050	NA	NA	50
Ammonia -N	ND	84.8	0.86	35.8	ND	ND	0.98	4.50	2.42	50.0	57.0	55.4	ND[3,4]	NA	0.50
Temperature (field)	12.8	9.3	8.1	11.1	17.7	18.5	8.1	8.0	5.5	8.8	8.8	8.8	12.8	12.6	
Metals															
Calcium	3.1	336	13.0	45.3	31.0	32.0	44.8	18.2	143	418	422	416	NA	NA	0.10
Chromium	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	0.03
Iron	ND	0.397	ND	5.94	ND	ND	ND	ND	0.051	0.037	ND	ND	NA	NA	0.030
Magnesium	2.3	18.7	1.80	12.1	3.5	2.9	1.89	0.262	3.60	5.81	15.6	15.2	NA	NA	0.100
Manganese	ND	4.32	ND	3.04	ND	ND	0.065	ND	0.623	0.486	5.13	5.02	NA	NA	0.010
Potassium	2.6	8.5	1.3	14.1	9.2	2.3	1.7	2.2	2.1	3.9	12.4	12.2	NA	NA	1.0
Sodium	4.2	157	25.8	74.4	44.0	18.0	14.3	4.01	4.60	47.8	68.1	66.4	NA	NA	0.50
SO_4 : Ca	11	3.2	2.1	1.2	2.0	1.1	2.4	2.1	1.0	2.8	2.5	3.3			
SO_4 : Alk	0.5	5.6	0.6	0.2	0.9	0.7	11	5.4	14	19	24	24			

Notes:
Screened Horizons:
- Shallow - Screened in upper unconsolidated materials
- Deep - Screened near top of bedrock and/or span top of bedrock

Bedrock private water supply well. Based on information provided by Sullivan and Lessard, their wells are approximately 450 feet and 700 feet in depth, respectively.

NA - Not analyzed for this parameter
ND - Analyzed for but not detected at practical quantitation limit
PQL - Practical Quantitation Limit

[a] estimate
[b] based upon auger refusal or encountered bedrock in ENSR well construction/boring log

* - Parameter obtained in the field, therefore, no practical quantitation limit is available
1 - Duplicate sample of MW-3
2 - Duplicate sample of SL-6
3 - Low water table. Purged dry (approx. 0.1 gallons) on 4/22/98. Sampled for sulfate on 4/23/98. Sampled for Ammonia 7/9/98
4 - Preliminary results

Table 2. Comparison between residential well (background) and GW-81D and GW-81BR groundwater chemistry (mg/L) for indicator compounds.

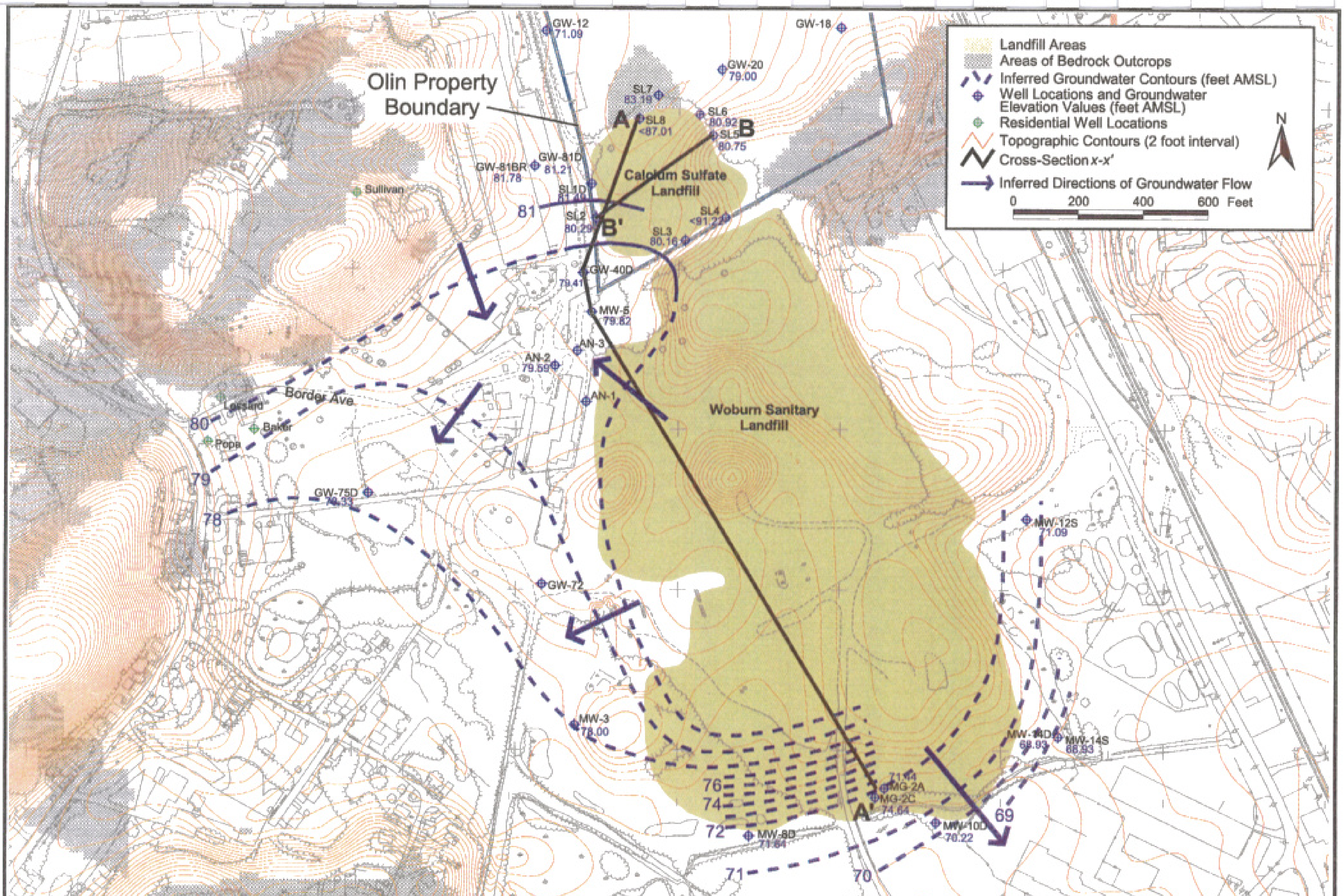
Archetypal CSL (SL-5) and WSL (MG-2A) well chemistries are shown for comparison.

	Baker	Lessard	Popa	Sullivan	background	GW - 81D	GW - 81BR	SL-5	MG - 2A
Alkalinity	8	94	106	34	61	50	72	88	1280
Ammonia	< 0.5	0.88	< 0.5	0.66	[a]0.5	< 0.5	< 0.5	50	158
Calcium	11	55	39	22	32	32	31	418	120
Chloride	76	46	21	60	51	29	46	23	110
Iron	0.037	0.038	< 0.03	0.052	[a]0.021	< 0.03	< 0.03	0.037	23
Sulfate	16	32	26	22	24	37	61	1190	14
Manganese	< 0.01	< 0.01	0.059	< 0.01	[a]0.019	< 0.01	< 0.01	[b]0.49	2.1

[a] Mean calculated using 1/2 the method detection limit

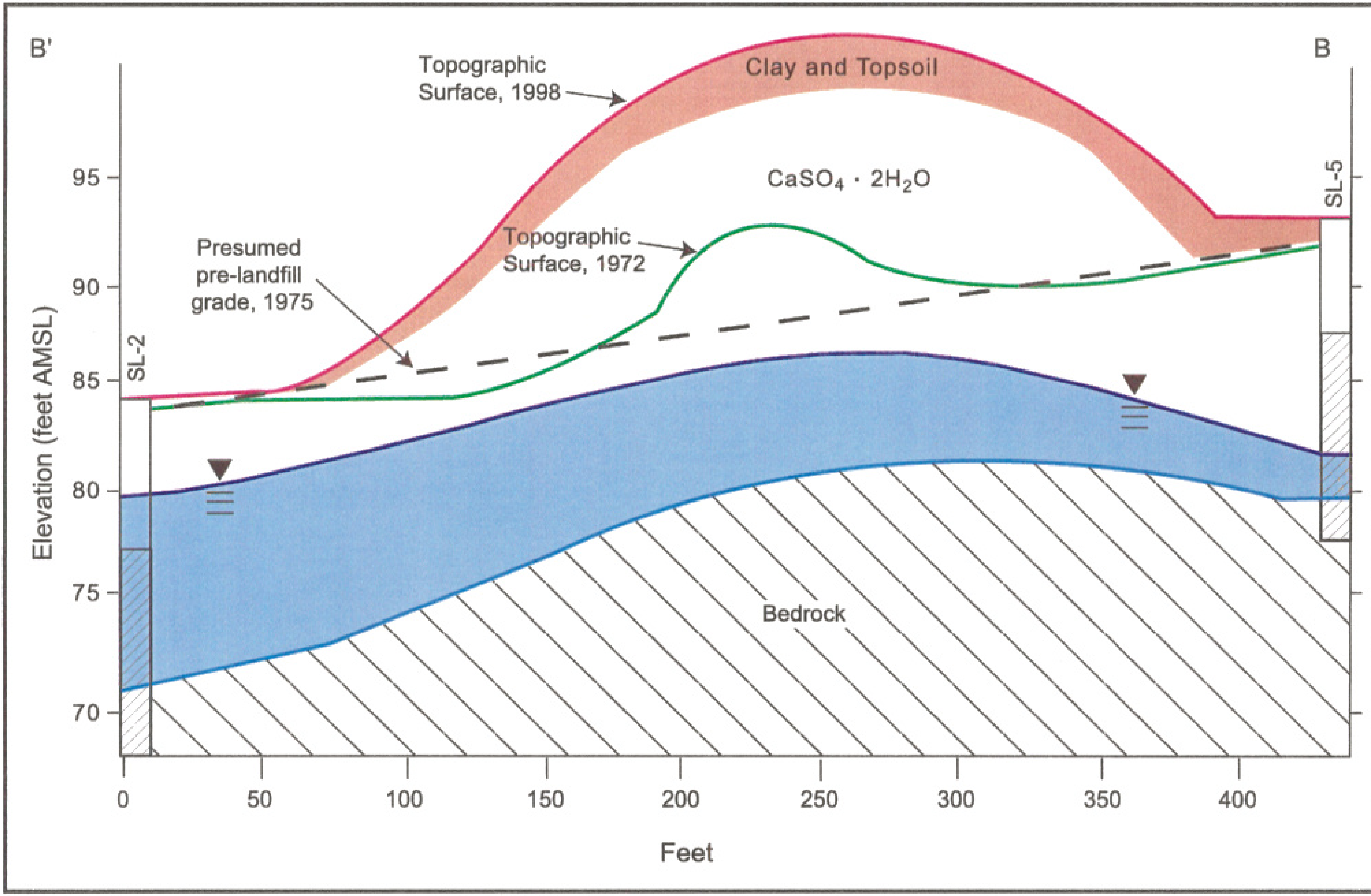
[b] Manganese in SL-6 averaged 5.1 mg/L

Figures



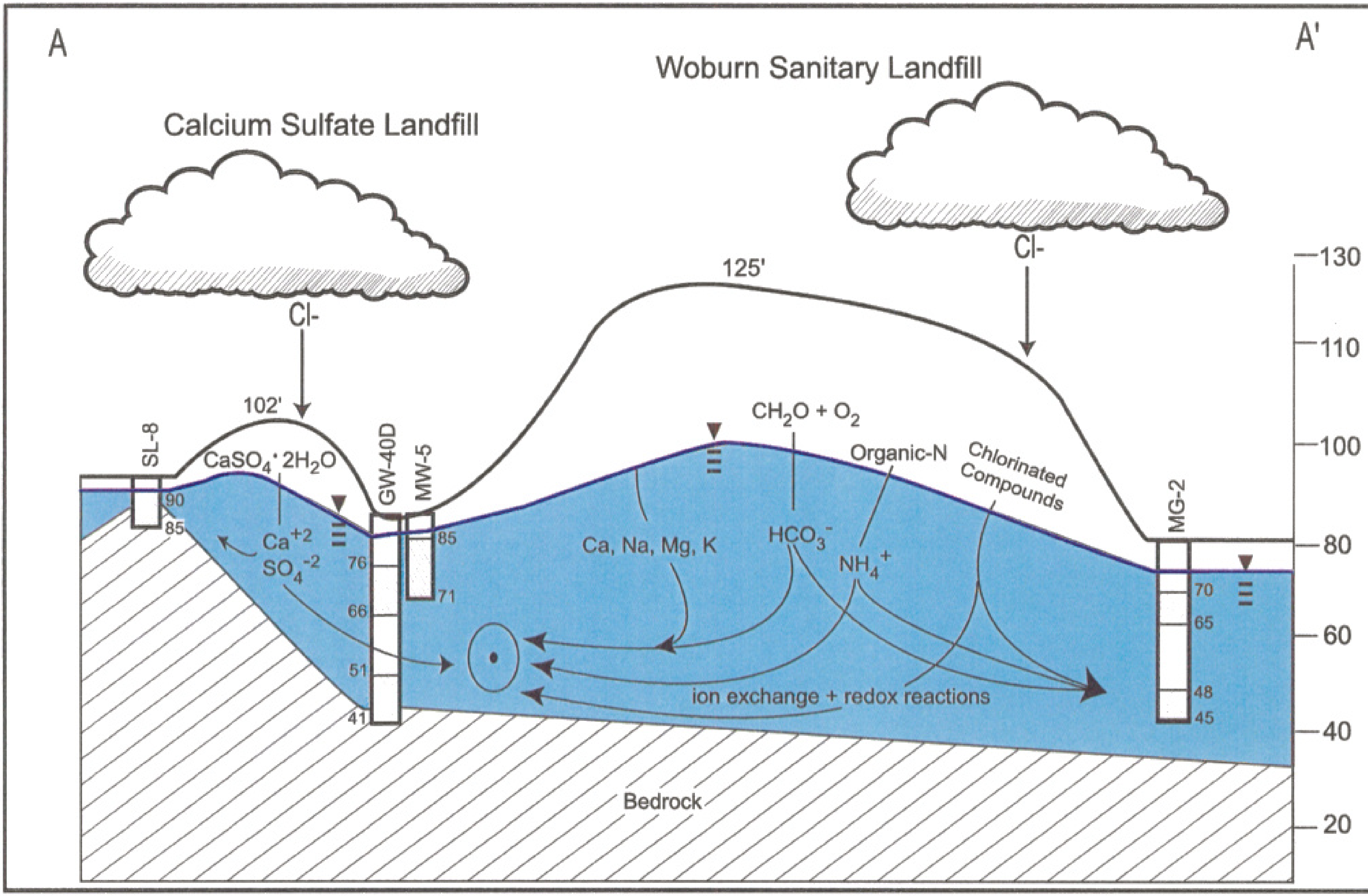
Generation Date: 2/8/99	Figure 1. Site Map Showing the Olin and Woburn Landfill Areas, Locations of Monitoring Wells, and Groundwater and Topographic Elevations. The Site Paradigm (Figure 3) is Drawn Along Cross-Section A-A'. The Woburn Landfill Perimeter is Based on the Extext of Refuse Defined by Fugro East (1996).	Geomega

\dg\L:\Projects\olin\so4landfill.apr: Fig1 layout-sitemap w/GW cont



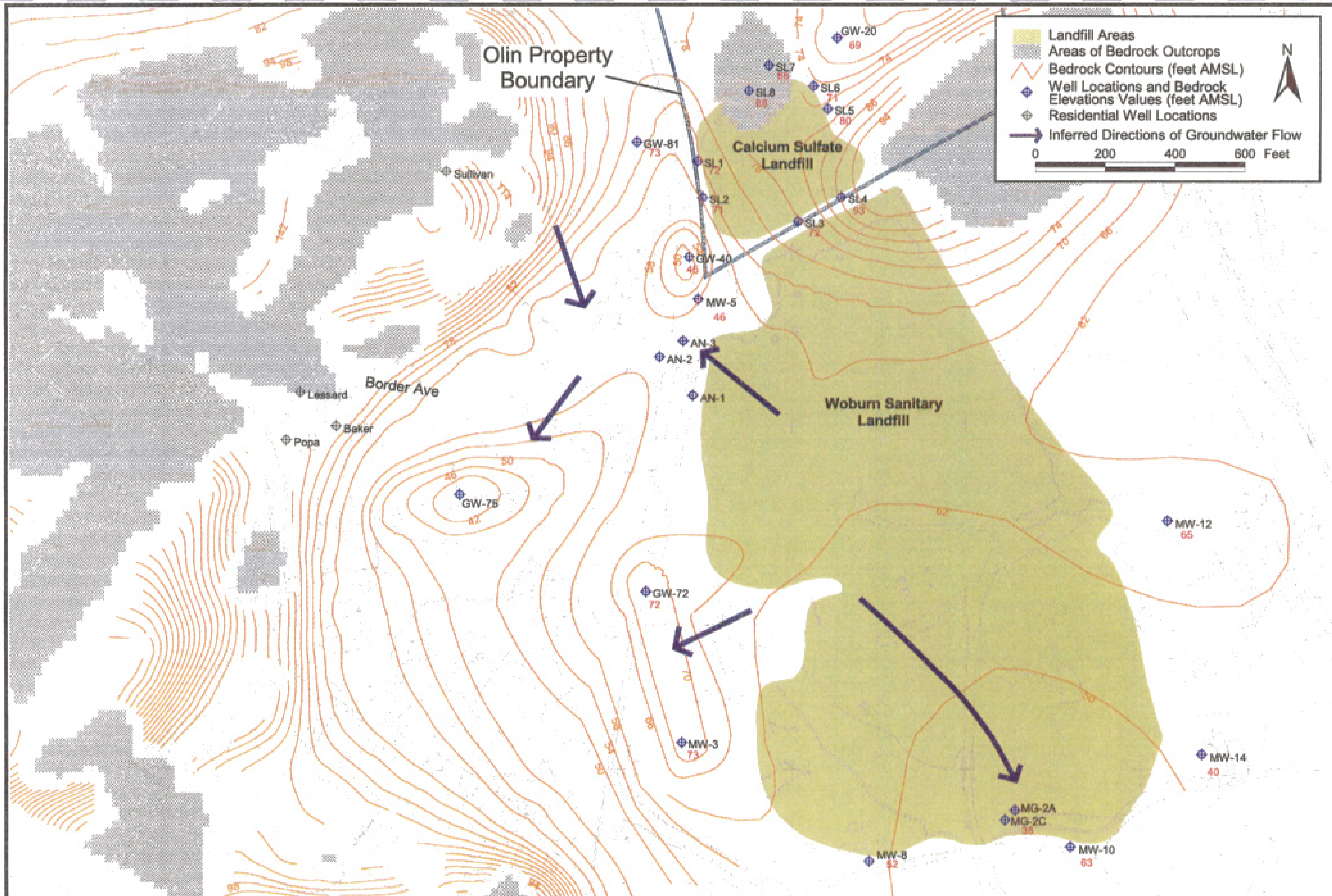
Generation Date: 2/8/99	Figure 2. Schematic Cross-Section of the CSL Showing Pre- and Post-Gypsum Emplacement (Vertical Exaggeration=8).	Geomega

o:\Olin\CalSulf02-08-99\CSL-reflected.ai



Generation Date: 2/8/99	Figure 3. Conceptual Landfill Geochemical Paradigm Along Transect A - A'. Well completion intervals in feet amsl.	Geomega

o:\Olin\CalSulf02-08-99\Woburn Landfill.ai

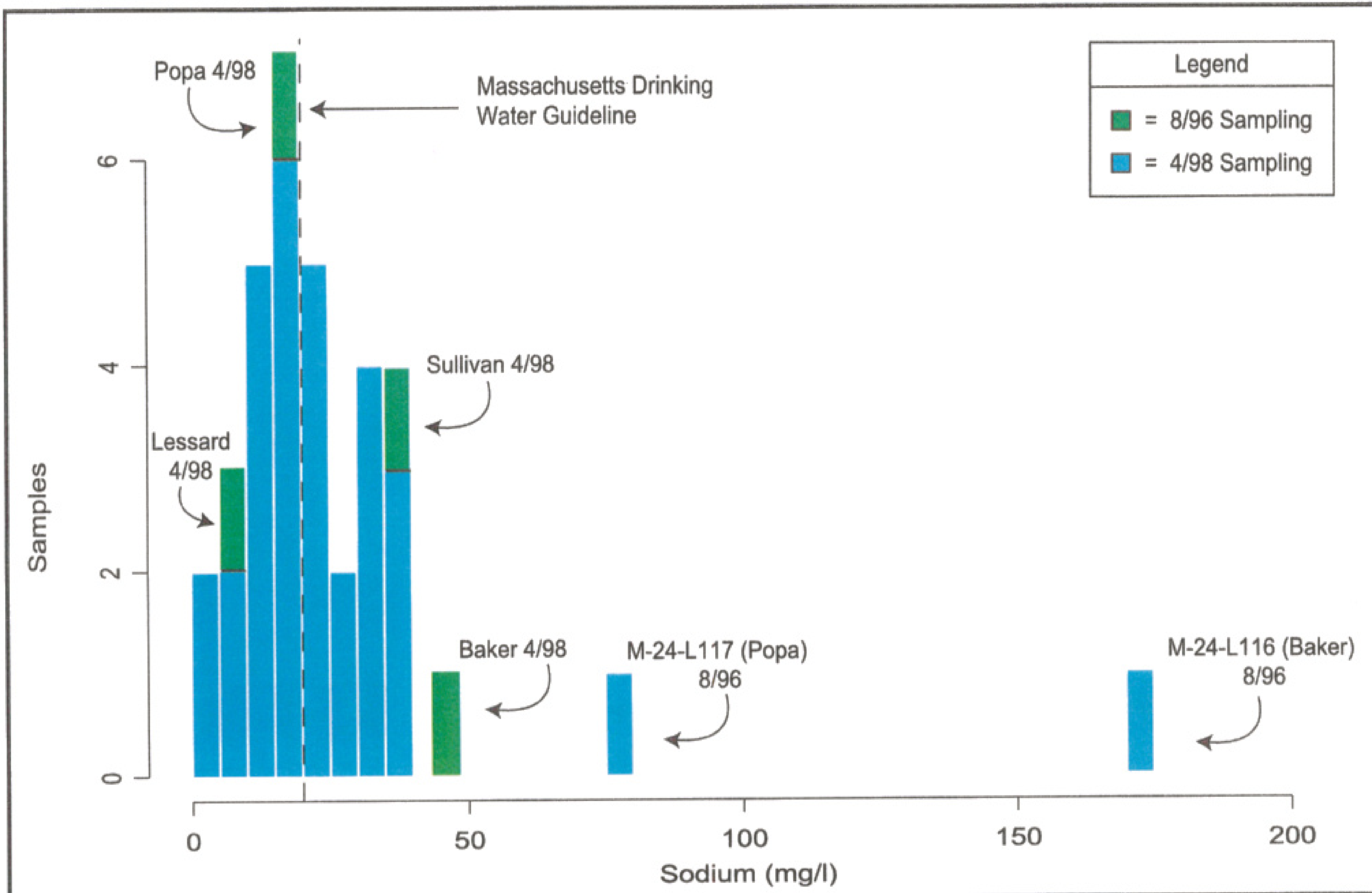


Generation Date: 2/8/99

Figure 4. Bedrock Elevations and General Directions of Groundwater Flow in the Vicinity of the Calcium Sulfate Landfill and the Woburn Sanitary Landfill.

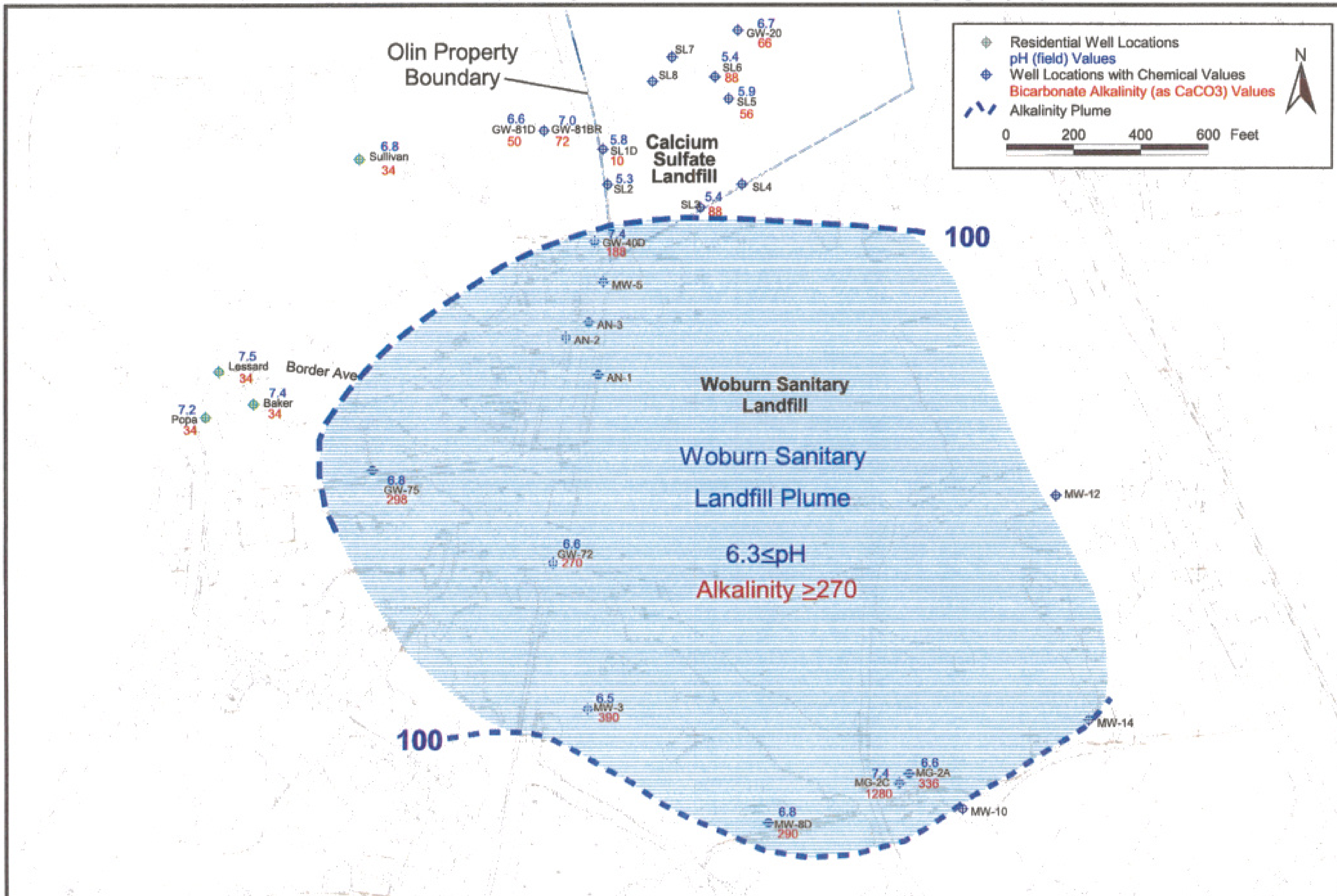
Geomega

\\dg\L:\Projects\olin\so4landfill.apr: Fig4 Layout-bedrock elev-merging troughs



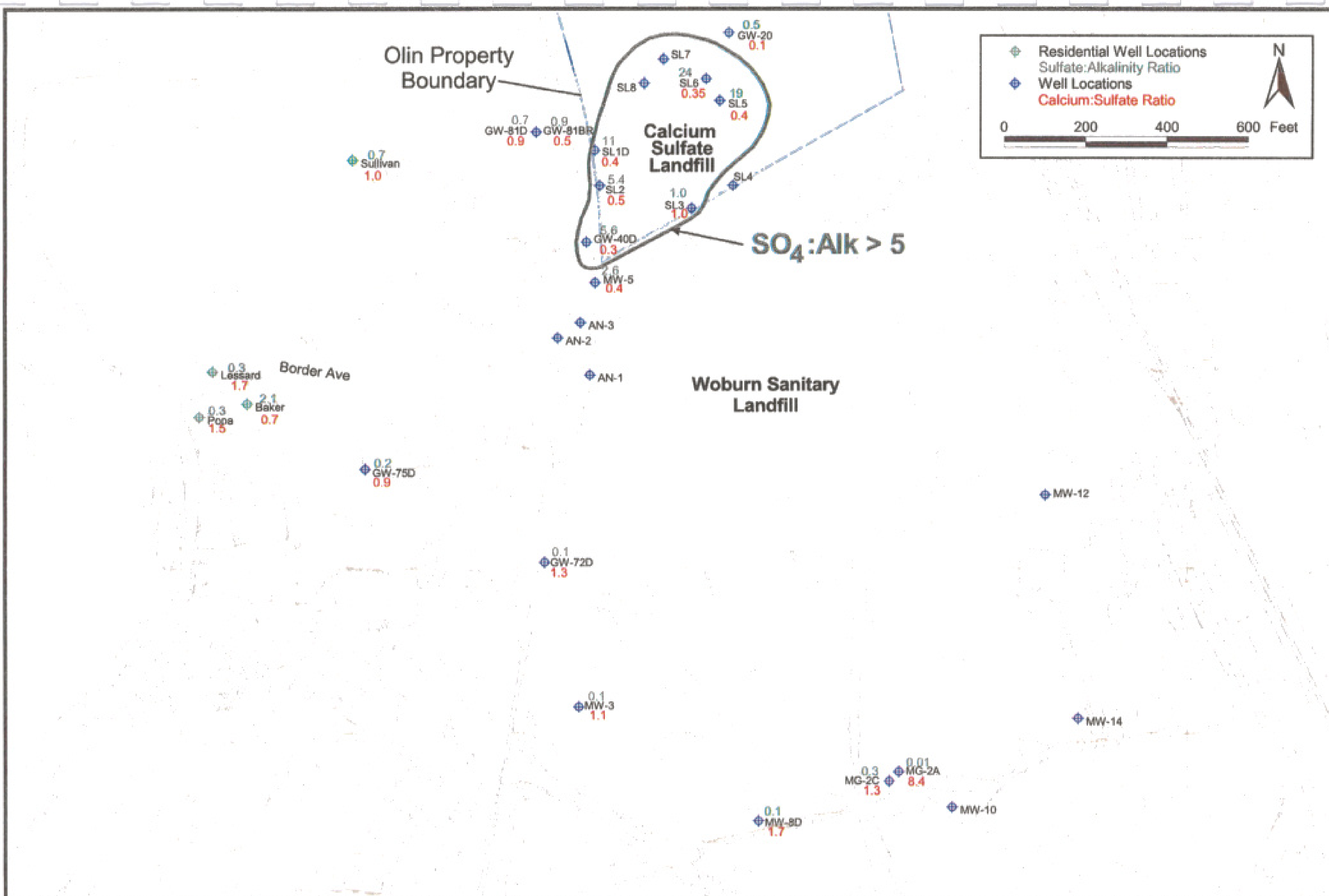
Generation Date: 2/8/99	Figure 5. Histogram of Sodium Concentrations, Residential Background Only.	Geomega

o:\Olin\CalSulf\02-08-99\NaBGHisto.ai



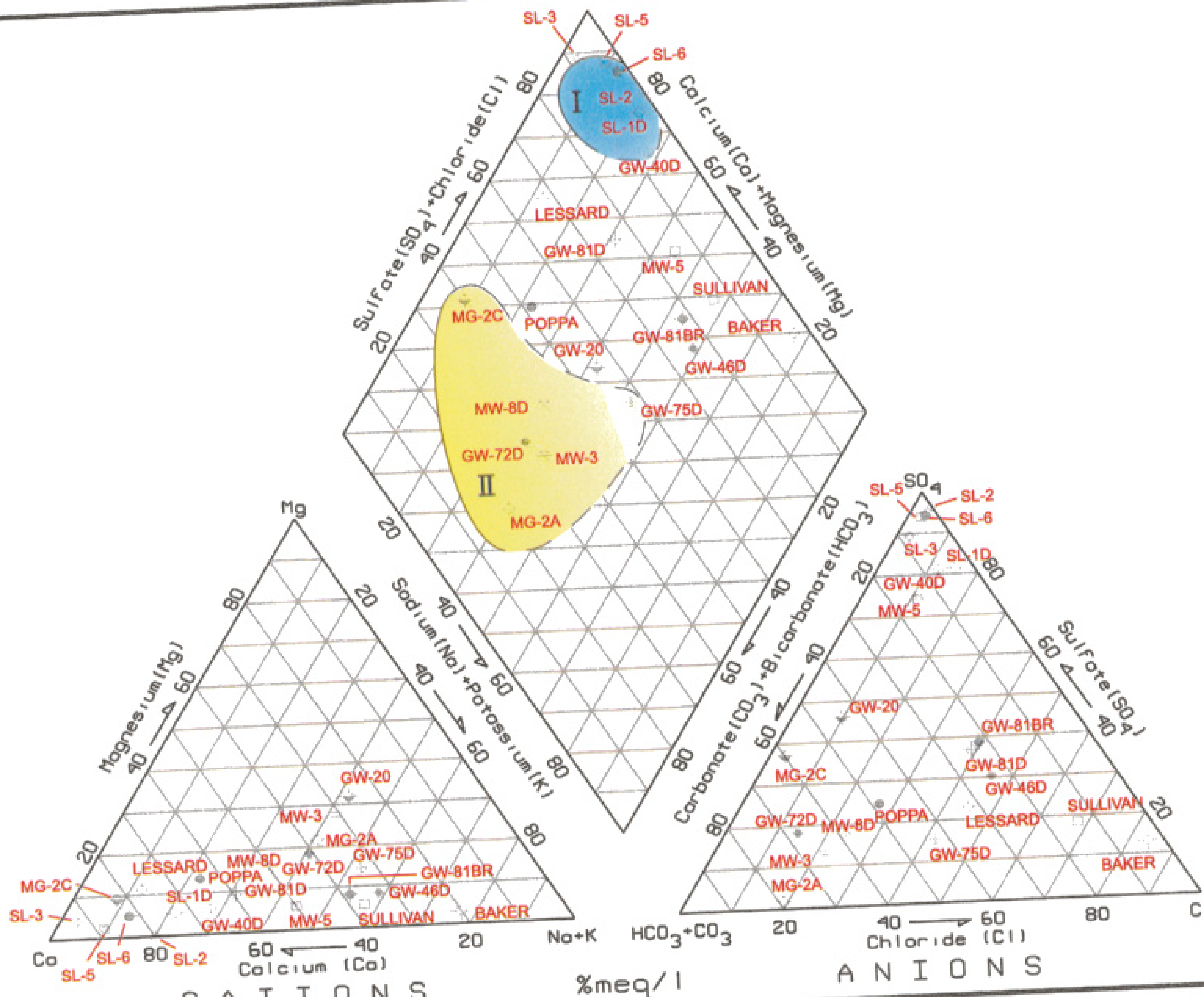
Generation Date: 2/8/99	Figure 8. Spatial Distribution of pH (s.u.) and Alkalinity (mg/l) in the Vicinity of the Landfills. AN-1, AN-2, AN-3 and MW-5 are Shallow Wells and are Excluded.	Geomega

\\dg\L:\Projects\olin\so4landfill.apr: Fig8 layout-pH&Alkalinity



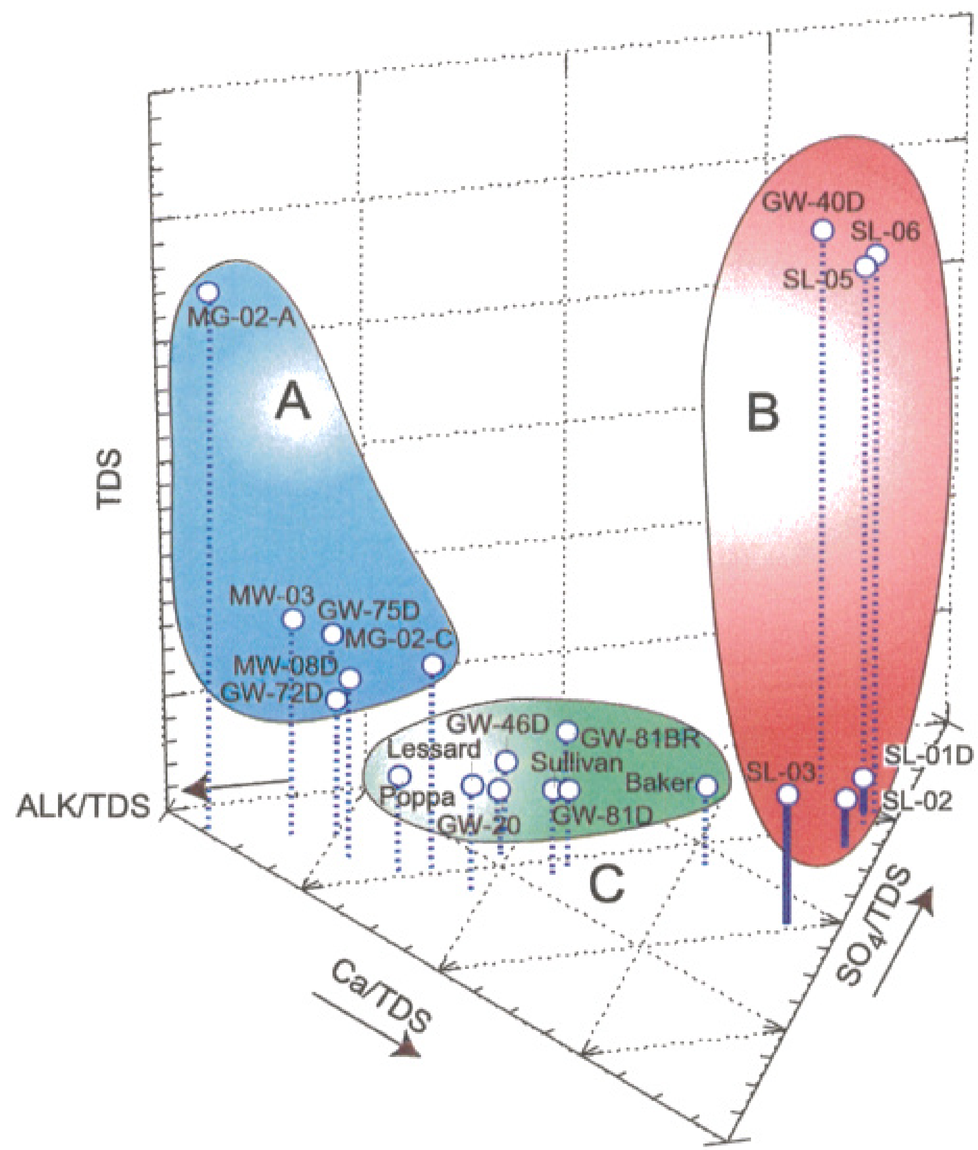
Generation Date: 2/8/99	Figure 9. Spatial Distribution of Sulfate: Calcium and Sulfate: Alkalinity Ratios in the Vicinity of the Landfills.	Geomega

\\dg\L:\Projects\olin\so4landfill.apr: 1/25/99 fig 9 layout sulfate: calcium&sulfate:alkalinity ratios



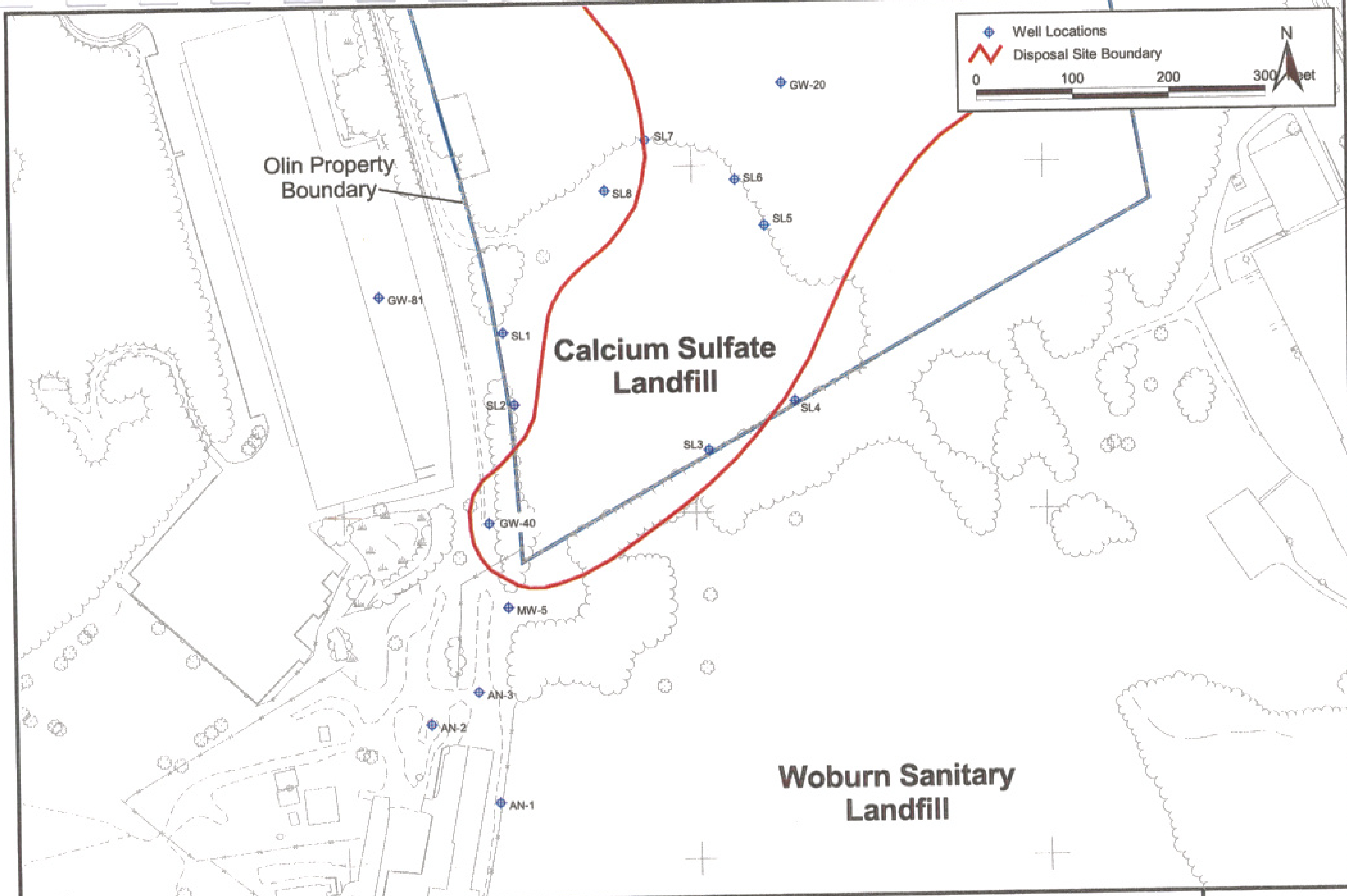
Generation Date: 2/8/99	Figure 10. Trilinear Diagram Demonstrating Discrimination Between the Calcium Sulfate/Woburn Sanitary Landfill - Related Groundwaters.	Geomega

o:\olin\CalSulf02-08-99\Piper.ai



Generation Date: 2/8/99	Figure 11. 3-D Quaternary Plot of Indication Elements Normalized to TDS in the CSL/WSL Area.	Geomega

o:\Olin\CalSulf02-08-99\3DTernaryPlot.ai



Generation Date: 2/8/99

Figure 12. Localized Disposal Site Boundary.

Geomega

\\dg\L:\Projects\olin\so4landfill.apr: Fig12 layout-localized site boundary 1/25/99

Appendix A

NATIONAL POLYCHEMICALS INC.
WILMINGTON MASSACHUSETTS 01887

JAN 12 1971

copy

wilmington solid waste

January 7, 1971

COPY

Mr. E. F. Romano
Director of Public Health
Board of Health
Town Hall
Wilmington, Massachusetts 01887

Dear Mr. Romano:

We are seeking approval from the Town of Wilmington for the disposal, as sanitary landfill, of calcium sulfate filter cake on land owned by National Polychemicals, Inc., and located at the Eames Street plant site. The filter cake results from the neutralization of the effluent with lime and subsequent filtration prior to the discharge of the aqueous effluent into the Metropolitan District Commission sewer line. It is projected that the landfill operation will consist of approximately 28 tons per day of wet filter cake, which contains about 50 percent water, and has a bulk density of 80 pounds per cubic foot.

The filter cake has the following tentative analysis:

Water	27,500 lbs.
Gypsum	26,800
$CaCO_3$	650
Calcium oxybisbenzene sulfonate	Trace*
Na_2SO_4	Trace*
$Al(OH)_3$	Trace*
NaCl	Trace*
$CaCl_2$	Trace*
Formaldehyde	Trace*
$NaNO_2$	Trace*
NH_4Cl	Trace*
TOTAL	54,950 lbs.

*Trace - Below 0.2%

We met with Mr. Kenneth A. Tarbell, District Sanitary Engineer, Commonwealth of Massachusetts, Department of Public Health, Northeastern Regional Health Office, on October 16, 1970, in reference to the landfill disposal of this filter cake. Since that date, we have made an inspection of the proposed site and feel that we have sufficient suitable area for

DEP 000382

disposal.

We would like to arrange a meeting at your earliest convenience for discussion of this proposal and for your inspection of the disposal site. If I can supply any further information, please contact me.

Very truly yours,

NATIONAL POLYCHEMICALS, INC.

Ronald J. McBrien

Ronald J. McBrien
Plant Manager

dfm

cc: Kenneth A. Tarbell
Charles W. Moores
CPR
ARG
RLW

COPY

Appendix B

SUMMARY OF PRIVATE WELL MONITORING DATA FOR BORDER AVENUE RESIDENCES AND COMPARISON TO MASSACHUSETTS DRINKING WATER STANDARDS/GUIDELINES

BAKER RESIDENCE
5 BORDER AVENUE

Parameter	Detected Concentrations			Drinking Water Standard/Guideline	Type of Standard/Guideline
	Oct-90	Aug-96	Apr-98		
Organics (ug/L)					
Di(2-ethylhexyl)phthalate	NS	1.3	NA	6	MMCL
Inorganics (mg/L)					
Antimony	NS	0.0061	NA	0.006	MMCL
Barium	NS	0.11	NA	2	MMCL
Calcium	NS	23.7	11.1	-	-
Iron	NS	0.042	0.037	0.3	SMCL
Lead	NS	0.0092	NA	0.015	MMCL
Magnesium	NS	2.75	1.21	-	-
Potassium	NS	1.83	1.6	-	-
Sodium	NS	129	46.7	20	ORSG
Chloride	NS	213	75.5	250	SMCL
Nitrate-N	NS	4.11	NA	10	MMCL
Sulfate	NS	25	16.4	250	SMCL
Other					
Alkalinity as $CaCO_3$ (mg/L)	NS	12	8	-	-
Total Dissolved Solids (mg/L)	NS	404	253	500	SMCL
pH	NS	5.49	5.68	6.5 - 8.5	SMCL

Notes:

NS - Not sampled

NA - Not analyzed

ND - Not detected

"-" indicates that no standard/guideline is available

MMCL - Massachusetts Drinking Water Standards, May 1998

SMCL - Secondary Maximum Contaminant Levels, May 1998

ORSG - Massachusetts Drinking Water Guidelines, May 1998

Shading indicates an exceedance of the standard/guideline for that parameter or that the measured pH is outside the SMCL range.

SUMMARY OF PRIVATE WELL MONITORING DATA FOR BORDER AVENUE RESIDENCES AND COMPARISON TO MASSACHUSETTS DRINKING WATER STANDARDS/GUIDELINES

POPA RESIDENCE
1 BORDER AVENUE

Parameter	Detected Concentrations			Drinking Water Standard/Guideline	Type of Standard/Guideline
	Oct-90	Aug-96	Apr-98		
Organics (ug/L)					
Dichlorodifluoromethane	NA	1	NA	1400	ORSG
Methylene Chloride	0.33	NS	NS	-	-
Diethylphthalate	73	NS	NS	-	-
MTBE	NA	30	NA	70	ORSG
Inorganics (mg/L)					
Barium	0.031	NS	NS	2	MMCL
Calcium	NA	53.6	38.8	-	-
Iron	0.091	0.1	ND	0.3	SMCL
Lead	NA	0.0056	NA	0.015	MMCL
Magnesium	NA	7.08	5.26	-	-
Manganese	NA	0.075	0.059	0.05	SMCL
Potassium	NA	1.87	1.3	-	-
Sodium	76	31.3	15.1	20	ORSG
Chloride	140	78.7	21.3	250	SMCL
Nitrate-N	2	0.51	NA	10	MMCL
Sulfate	19	30	26.3	250	SMCL
Other					
Alkalinity as $CaCO_3$ (mg/L)	NA	84	106	-	-
Total Dissolved Solids (mg/L)	NA	316	148	500	SMCL
pH	NA	7.3	7.69	6.5 - 8.5	SMCL

Notes:

NS - Not sampled

NA - Not analyzed

ND - Not detected

"-" indicates that no standard/guideline is available

MMCL - Massachusetts Drinking Water Standards, May 1998

SMCL - Secondary Maximum Contaminant Levels, May 1998

ORSG - Massachusetts Drinking Water Guidelines, May 1998

Shading indicates an exceedance of the standard/guideline for that parameter or that the measured pH is outside the SMCL range.

SUMMARY OF PRIVATE WELL MONITORING DATA FOR BORDER AVENUE RESIDENCES AND COMPARISON TO MASSACHUSETTS DRINKING WATER STANDARDS/GUIDELINES

LESSARD RESIDENCE

9 BORDER AVENUE

Parameter	Detected Concentrations			Drinking Water Standard/Guideline	Type of Standard/Guideline
	Oct-90	Aug-96	Apr-98		
Organics (ug/L)					
Chloroform	0.53	ND	NA	-	-
Dichlorodifluoromethane	ND	1	NA	1400	ORSG
Methylene Chloride	0.42	NA	NA	-	-
MTBE	NA	30	NA	70	ORSG
Tetrachloroethene	0.1	ND	NA	5	MMCL
Di(2-ethylhexyl)phthalate	ND	1.2	NA	6	MMCL
Inorganics (mg/L)					
Barium	0.017	ND	NA	2	MMCL
Calcium	NA	71.5	54.5	-	-
Copper	0.036	ND	NA	1.3/1	MMCL/SMCL
Iron	ND	0.097	0.038	0.3	SMCL
Magnesium	NA	5.89	4.9	-	-
Potassium	NA	1.48	1.6	-	-
Sodium	4.8	32.6	9.3	20	ORSG
Zinc	0.058	ND	NA	5	SMCL
Ammonia-N	ND	ND	0.88	-	-
Chloride	6.9	103	45.7	250	SMCL
Nitrate-N	4.2	0.97	NA	10	MMCL
Sulfate	9.4	30	31.8	250	SMCL
Other					
Alkalinity as $CaCO_3$ (mg/L)	NA	106	94	-	-
Total Dissolved Solids (mg/L)	NA	338	265	500	SMCL
pH	NA	7.11	7.59	6.5 - 8.5	SMCL

Notes:

NS - Not sampled

NA - Not analyzed

ND - Not detected

"-" indicates that no standard/guideline is available

MMCL - Massachusetts Drinking Water Standards, May 1998

SMCL - Secondary Maximum Contaminant Levels, May 1998

ORSG - Massachusetts Drinking Water Guidelines, May 1998

Shading indicates an exceedance of the standard/guideline for that parameter or that the measured pH is outside the SMCL range.

12/18/98 2:

SUMMARY OF PRIVATE WELL MONITORING DATA FOR BORDER AVENUE RESIDENCES AND COMPARISON TO MASSACHUSETTS DRINKING WATER STANDARDS/GUIDELINES

SULLIVAN RESIDENCE
3 BORDER AVENUE

Parameter	Detected Concentrations			Drinking Water Standard/Guideline	Type of Standard/Guideline
	Oct-90	Aug-96	Apr-98		
Organics (ug/L)					
Methylene Chloride	0.32	NA	NA	-	-
MTBE	NA	60	NA	70	ORSG
Di(2-ethylhexyl)phthalate	ND	1	NA	6	MMCL
Inorganics (mg/L)					
Barium	0.007	ND	NA	2	MMCL
Calcium	NA	52.5	22.4	-	-
Copper	ND	0.036	NA	1.3/1	MMCL/SMCL
Iron	0.22	0.041	0.052	0.3	SMCL
Magnesium	NA	5.6	1.97	-	-
Potassium	NA	2.62	2.6	-	-
Sodium	28	38.7	36.6	20	ORSG
Zinc	0.05	0.03	NA	5	SMCL
Ammonia-N	ND	ND	0.66	-	-
Chloride	54	107	59.6	250	SMCL
Nitrate-N	5.1	3.25	NA	10	MMCL
Sulfate	27	21	22.2	250	SMCL
Other					
Alkalinity as $CaCO_3$ (mg/L)	NA	74	34	-	-
Total Dissolved Solids (mg/L)	NA	328	80	500	SMCL
pH	NA	6.89	6.3	6.5 - 8.5	SMCL

Notes:

NS - Not sampled

NA - Not analyzed

ND - Not detected

"-" indicates that no standard/guideline is available

MMCL - Massachusetts Drinking Water Standards, May 1998

SMCL - Secondary Maximum Contaminant Levels, May 1998

ORSG - Massachusetts Drinking Water Guidelines, May 1998

Shading indicates an exceedance of the standard/guideline for that parameter or that the measured pH is outside the SMCL range.

Appendix C

Appendix C
PHREEQC Model Results for GW-40D at pH 7.42 and 6.82

Model Input

pH	6.82
density	1.00
temp	25
units	ppm
Alkalinity	115 as HCO3
Ca	336
Cl	117 charge
Cr(3)	0
Fe(2)	0.397
Mg	18.7
Mn(2)	4.32
N	84.8
Na	157
S(6)	1061

Solution Composition

Elements	Molality	Moles		Final mg/L
Alkalinity	1.888e-03	1.888e-03		109 as HCO3
Ca	8.400e-03	8.400e-03		336
Cl	8.138e-03	8.138e-03	Charge balance	
Fe(2)	7.123e-06	7.123e-06		
Mg	7.707e-04	7.707e-04		
Mn(2)	7.879e-05	7.879e-05		
N	6.066e-03	6.066e-03		
Na	6.843e-03	6.843e-03		
S(6)	1.107e-02	1.107e-02		776 as SO4

Description of Solution

pH = 6.820
pe = 4.000
Activity of water = 0.999
Ionic strength = 4.046e-02
Mass of water (kg) = 1.000e+00
Total carbon (mol/kg) = 2.376e-03
Total CO2 (mol/kg) = 2.376e-03
Temperature (deg C) = 25.000
Electrical balance (eq) = -3.194e-12
Iterations = 11
Total H = 1.110396e+02
Total O = 5.555761e+01

Distribution of Species

	Species	Molality	Activity	Molality	Activity	Gamma
	H+	1.756e-07	1.514e-07	-6.756	-6.820	-0.064
	OH-	8.038e-08	6.633e-08	-7.095	-7.178	-0.083
	H2O	5.551e+01	9.993e-01	0.000	0.000	0.000
C(4)	2.376e-03	109 mg/L as HCO3				
	HCO3-	1.795e-03	1.508e-03	-2.746	-2.822	-0.076
	H2CO3	5.079e-04	5.126e-04	-3.294	-3.290	0.004
	CaHCO3+	5.703e-05	4.814e-05	-4.244	-4.317	-0.074
	MgHCO3+	6.350e-06	5.266e-06	-5.197	-5.278	-0.081
	NaHCO3	4.713e-06	4.757e-06	-5.327	-5.323	0.004
	CaCO3	2.023e-06	2.042e-06	-5.694	-5.690	0.004
	MnHCO3+	9.778e-07	8.145e-07	-6.010	-6.089	-0.079
	CO3-2	9.367e-07	4.665e-07	-6.028	-6.331	-0.303
	MgCO3	1.310e-07	1.322e-07	-6.883	-6.879	0.004
	NaCO3-	5.768e-08	4.845e-08	-7.239	-7.315	-0.076
Ca	8.399e-03	336 mg/L				
	Ca+2	5.973e-03	3.081e-03	-2.224	-2.511	-0.288
	CaSO4	2.367e-03	2.389e-03	-2.626	-2.622	0.004
	CaHCO3+	5.703e-05	4.814e-05	-4.244	-4.317	-0.074
	CaCO3	2.023e-06	2.042e-06	-5.694	-5.690	0.004
	CaOH+	6.080e-09	5.133e-09	-8.216	-8.290	-0.074
Cl	7.399e-03					
	Cl-	7.398e-03	6.081e-03	-2.131	-2.216	-0.085
	MnCl+	8.518e-07	7.130e-07	-6.070	-6.147	-0.077
	MnCl2	1.167e-09	1.178e-09	-8.933	-8.929	0.004
	MnCl3-	3.858e-12	3.229e-12	-11.414	-11.491	-0.077
Fe(2)	7.122e-06					
	Fe+2	5.308e-06	2.696e-06	-5.275	-5.569	-0.294
	FeSO4	1.808e-06	1.825e-06	-5.743	-5.739	0.004
	FeOH+	6.723e-09	5.628e-09	-8.172	-8.250	-0.077
	Fe(OH)2	3.134e-13	3.163e-13	-12.504	-12.500	0.004
	Fe(OH)3-	9.268e-17	7.759e-17	-16.033	-16.110	-0.077
H(0)	3.214e-25					
	H2	1.607e-25	1.622e-25	-24.794	-24.790	0.004
Mg	7.706e-04					
	Mg+2	5.650e-04	2.970e-04	-3.248	-3.527	-0.279
	MgSO4	1.992e-04	2.010e-04	-3.701	-3.697	0.004
	MgHCO3+	6.350e-06	5.266e-06	-5.197	-5.278	-0.081
	MgCO3	1.310e-07	1.322e-07	-6.883	-6.879	0.004
	MgOH+	3.800e-09	3.220e-09	-8.420	-8.492	-0.072
Mn(2)	7.878e-05					
	Mn+2	5.706e-05	2.898e-05	-4.244	-4.538	-0.294
	MnSO4	1.989e-05	2.007e-05	-4.701	-4.697	0.004
	MnHCO3+	9.778e-07	8.145e-07	-6.010	-6.089	-0.079
	MnCl+	8.518e-07	7.130e-07	-6.070	-6.147	-0.077
	MnOH+	5.875e-09	4.918e-09	-8.231	-8.308	-0.077
	MnCl2	1.167e-09	1.178e-09	-8.933	-8.929	0.004
	MnCl3-	3.858e-12	3.229e-12	-11.414	-11.491	-0.077
	Mn(OH)3-	1.579e-19	1.322e-19	-18.802	-18.879	-0.077
	Mn(NO3)2	0.000e+00	0.000e+00	-46.351	-46.347	0.004
N(-3)	6.066e-03					
	NH4+	5.772e-03	4.712e-03	-2.239	-2.327	-0.088
	NH4SO4-	2.760e-04	2.311e-04	-3.559	-3.636	-0.077
	NH3	1.758e-05	1.774e-05	-4.755	-4.751	0.004

N(3)	6.381e-15				
NO2-	6.381e-15	5.316e-15	-14.195	-14.274	-0.079
N(5)	7.604e-22				
NO3-	7.604e-22	6.242e-22	-21.119	-21.205	-0.086
Mn(NO3)2	0.000e+00	0.000e+00	-46.351	-46.347	0.004
Na	6.842e-03				
Na+	6.710e-03	5.604e-03	-2.173	-2.251	-0.078
NaSO4-	1.273e-04	1.069e-04	-3.895	-3.971	-0.076
NaHCO3	4.713e-06	4.757e-06	-5.327	-5.323	0.004
NaCO3-	5.768e-08	4.845e-08	-7.239	-7.315	-0.076
O(0)	0.000e+00				
O2	0.000e+00	0.000e+00	-42.805	-42.801	0.004
S(6)	1.107e-02	776 mg/L as SO4			
SO4-2	8.075e-03	3.807e-03	-2.093	-2.419	-0.327
CaSO4	2.367e-03	2.389e-03	-2.626	-2.622	0.004
NH4SO4-	2.760e-04	2.311e-04	-3.559	-3.636	-0.077
MgSO4	1.992e-04	2.010e-04	-3.701	-3.697	0.004
NaSO4-	1.273e-04	1.069e-04	-3.895	-3.971	-0.076
MnSO4	1.989e-05	2.007e-05	-4.701	-4.697	0.004
FeSO4	1.808e-06	1.825e-06	-5.743	-5.739	0.004
HSO4-	6.709e-08	5.591e-08	-7.173	-7.253	-0.079

Saturation indices

Phase	SI	Log IAP	Log KT	
Anhydrite	-0.29	-4.93	-4.64	CaSO4
Aragonite	-0.51	-8.84	-8.34	CaCO3
Artinite	-9.35	0.25	9.60	MgCO3:Mg(OH)2:3H2O
Brucite	-6.68	10.11	16.79	Mg(OH)2
Calcite	-0.37	-8.84	-8.47	CaCO3
CH4(g)	-66.43	-106.53	-40.10	CH4
CO2(g)	-1.81	-19.97	-18.16	CO2
Dolomite	-1.70	-18.70	-17.00	CaMg(CO3)2
Epsomite	-3.81	-5.95	-2.14	MgSO4:7H2O
Gypsum	-0.08	-4.93	-4.85	CaSO4:2H2O
Halite	-6.05	-4.47	1.58	NaCl
Hausmannite	-12.59	48.95	61.54	Mn3O4
Huntite	-8.45	-38.42	-29.97	CaMg3(CO3)4
Hydromagnesite	-20.56	-29.32	-8.77	Mg5(CO3)4(OH)2:4H2O
Lime	-21.67	11.13	32.80	CaO
Magnesite	-1.83	-9.86	-8.03	MgCO3
Melanterite	-5.52	-7.99	-2.47	FeSO4:7H2O
Mirabilite	-5.81	-6.93	-1.11	Na2SO4:10H2O
MnCl2:4H2O	-11.68	-8.97	2.71	MnCl2:4H2O
MnSO4	-9.63	-6.96	2.67	MnSO4
Natron	-9.53	-10.84	-1.31	Na2CO3:10H2O
Nesquehonite	-4.24	-9.86	-5.62	MgCO3:3H2O
O2(g)	-39.84	43.28	83.12	O2
Periclase	-11.40	10.11	21.51	MgO
Portlandite	-11.55	11.13	22.68	Ca(OH)2
Pyrocroite	-5.99	9.10	15.09	Mn(OH)2
Rhodochrosite	-0.46	-10.87	-10.41	MnCO3
Siderite	-1.35	-11.90	-10.55	FeCO3
Thenardite	-6.74	-6.92	-0.18	Na2SO4
Thermonatrite	-10.96	-10.83	0.12	Na2CO3:H2O

Model Input

pH	7.42
density	1.00
temp	25
units	ppm
Alkalinity	115 as HCO3
Ca	336
Cl	117 charge
Cr(3)	0
Fe(2)	0.397
Mg	18.7
Mn(2)	4.32
N	84.8
Na	157
S(6)	1061

Solution Composition

Elements	Molality	Moles		Final mg/L
Alkalinity	1.888e-03	1.888e-03		105 as HCO3
Ca	8.400e-03	8.400e-03		336
Cl	8.138e-03	8.138e-03	Charge balance	
Fe(2)	7.122e-06	7.122e-06		
Mg	7.707e-04	7.707e-04		
Mn(2)	7.879e-05	7.879e-05		
N	6.066e-03	6.066e-03		
Na	6.843e-03	6.843e-03		
S(6)	1.107e-02	1.107e-02		776 as SO4

Description of Solution

pH = 7.420
pe = 4.000
Activity of water = 0.999
Ionic strength = 4.037e-02
Mass of water (kg) = 1.000e+00
Total carbon (mol/kg) = 1.929e-03
Total CO2 (mol/kg) = 1.929e-03
Temperature (deg C) = 25.000
Electrical balance (eq) = -4.856e-12
Iterations = 10
Total H = 1.110387e+02
Total O = 5.555627e+01

Distribution of Species

	Species	Molality	Activity	Log Molality	Log Activity	Log Gamma
	OH-	3.199e-07	2.641e-07	-6.495	-6.578	-0.083
	H+	4.409e-08	3.802e-08	-7.356	-7.420	-0.064
	H2O	5.551e+01	9.993e-01	0.000	0.000	0.000
C(4)	1.929e-03	105 mg/L HCO3				
	HCO3-	1.728e-03	1.452e-03	-2.762	-2.838	-0.076
	H2CO3	1.228e-04	1.239e-04	-3.911	-3.907	0.004
	CaHCO3+	5.486e-05	4.632e-05	-4.261	-4.334	-0.074
	CaCO3	7.748e-06	7.820e-06	-5.111	-5.107	0.004
	MgHCO3+	6.110e-06	5.068e-06	-5.214	-5.295	-0.081
	NaHCO3	4.537e-06	4.579e-06	-5.343	-5.339	0.004
	CO3-2	3.588e-06	1.787e-06	-5.445	-5.748	-0.303
	MnHCO3+	9.413e-07	7.843e-07	-6.026	-6.106	-0.079
	MgCO3	5.018e-07	5.064e-07	-6.300	-6.295	0.004
	NaCO3-	2.210e-07	1.857e-07	-6.656	-6.731	-0.076
Ca	8.399e-03	336mg/L				
	Ca+2	5.969e-03	3.080e-03	-2.224	-2.511	-0.287
	CaSO4	2.368e-03	2.390e-03	-2.626	-2.622	0.004
	CaHCO3+	5.486e-05	4.632e-05	-4.261	-4.334	-0.074
	CaCO3	7.748e-06	7.820e-06	-5.111	-5.107	0.004
	CaOH+	2.420e-08	2.043e-08	-7.616	-7.690	-0.074
Cl	7.399e-03					
	Cl-	7.398e-03	6.082e-03	-2.131	-2.216	-0.085
	MnCl+	8.521e-07	7.134e-07	-6.070	-6.147	-0.077
	MnCl2	1.168e-09	1.179e-09	-8.933	-8.929	0.004
	MnCl3-	3.860e-12	3.232e-12	-11.413	-11.491	-0.077
Fe(2)	7.122e-06					
	Fe+2	5.291e-06	2.688e-06	-5.276	-5.570	-0.294
	FeSO4	1.804e-06	1.821e-06	-5.744	-5.740	0.004
	FeOH+	2.669e-08	2.235e-08	-7.574	-7.651	-0.077
	Fe(OH)2	4.953e-12	4.999e-12	-11.305	-11.301	0.004
	Fe(OH)3-	5.832e-15	4.882e-15	-14.234	-14.311	-0.077
H(0)	2.028e-26					
	H2	1.014e-26	1.023e-26	-25.994	-25.990	0.004
Mg	7.706e-04					
	Mg+2	5.647e-04	2.969e-04	-3.248	-3.527	-0.279
	MgSO4	1.993e-04	2.011e-04	-3.701	-3.697	0.004
	MgHCO3+	6.110e-06	5.068e-06	-5.214	-5.295	-0.081
	MgCO3	5.018e-07	5.064e-07	-6.300	-6.295	0.004
	MgOH+	1.512e-08	1.282e-08	-7.820	-7.892	-0.072
Mn(2)	7.878e-05					
	Mn+2	5.706e-05	2.899e-05	-4.244	-4.538	-0.294
	MnSO4	1.991e-05	2.009e-05	-4.701	-4.697	0.004
	MnHCO3+	9.413e-07	7.843e-07	-6.026	-6.106	-0.079
	MnCl+	8.521e-07	7.134e-07	-6.070	-6.147	-0.077
	MnOH+	2.340e-08	1.959e-08	-7.631	-7.708	-0.077
	MnCl2	1.168e-09	1.179e-09	-8.933	-8.929	0.004
	MnCl3-	3.860e-12	3.232e-12	-11.413	-11.491	-0.077
	Mn(OH)3-	9.966e-18	8.344e-18	-17.001	-17.079	-0.077
	Mn(NO3)2	4.380e-35	4.421e-35	-34.359	-34.355	0.004
N(-3)	6.066e-03					
	NH4+	5.723e-03	4.672e-03	-2.242	-2.331	-0.088
	NH4SO4-	2.738e-04	2.293e-04	-3.563	-3.640	-0.077
	NH3	6.938e-05	7.003e-05	-4.159	-4.155	0.004

N(3)	3.992e-10					
	NO2-	3.992e-10	3.326e-10	-9.399	-9.478	-0.079
N(5)	7.539e-16					
	NO3-	7.539e-16	6.189e-16	-15.123	-15.208	-0.086
	Mn(NO3)2	4.380e-35	4.421e-35	-34.359	-34.355	0.004
Na	6.842e-03					
	Na+	6.710e-03	5.605e-03	-2.173	-2.251	-0.078
	NaSO4-	1.274e-04	1.070e-04	-3.895	-3.971	-0.076
	NaHCO3	4.537e-06	4.579e-06	-5.343	-5.339	0.004
	NaCO3-	2.210e-07	1.857e-07	-6.656	-6.731	-0.076
O(0)	0.000e+00					
	O2	0.000e+00	0.000e+00	-40.405	-40.401	0.004
S(6)	1.107e-02	776 mg/L SO4				
	SO4-2	8.076e-03	3.809e-03	-2.093	-2.419	-0.326
	CaSO4	2.368e-03	2.390e-03	-2.626	-2.622	0.004
	NH4SO4-	2.738e-04	2.293e-04	-3.563	-3.640	-0.077
	MgSO4	1.993e-04	2.011e-04	-3.701	-3.697	0.004
	NaSO4-	1.274e-04	1.070e-04	-3.895	-3.971	-0.076
	MnSO4	1.991e-05	2.009e-05	-4.701	-4.697	0.004
	FeSO4	1.804e-06	1.821e-06	-5.744	-5.740	0.004
	HSO4-	1.686e-08	1.405e-08	-7.773	-7.852	-0.079

Saturation indices

Phase	SI	Log IAP	Log KT	
Anhydrite	-0.29	-4.93	-4.64	CaSO4
Aragonite	0.08	-8.26	-8.34	CaCO3
Artinite	-7.56	2.04	9.60	MgCO3:Mg(OH)2:3H2O
Brucite	-5.48	11.31	16.79	Mg(OH)2
Calcite	0.22	-8.26	-8.47	CaCO3
CH4(g)	-71.85	-111.95	-40.10	CH4
CO2(g)	-2.43	-20.59	-18.16	CO2
Dolomite	-0.53	-17.53	-17.00	CaMg(CO3)2
Epsomite	-3.81	-5.95	-2.14	MgSO4:7H2O
Gypsum	-0.08	-4.93	-4.85	CaSO4:2H2O
Halite	-6.05	-4.47	1.58	NaCl
Hausmannite	-7.79	53.75	61.54	Mn3O4
Huntite	-6.12	-36.08	-29.97	CaMg3(CO3)4
Hydromagnesite	-17.02	-25.79	-8.77	Mg5(CO3)4(OH)2:4H2O
Lime	-20.47	12.33	32.80	CaO
Magnesite	-1.25	-9.28	-8.03	MgCO3
Melanterite	-5.52	-7.99	-2.47	FeSO4:7H2O
Mirabilite	-5.81	-6.92	-1.11	Na2SO4:10H2O
MnCl2:4H2O	-11.68	-8.97	2.71	MnCl2:4H2O
MnSO4	-9.63	-6.96	2.67	MnSO4
Natron	-8.94	-10.25	-1.31	Na2CO3:10H2O
Nesquehonite	-3.66	-9.28	-5.62	MgCO3:3H2O
O2(g)	-37.44	45.68	83.12	O2
Periclase	-10.20	11.31	21.51	MgO
Portlandite	-10.35	12.33	22.68	Ca(OH)2
Pyrocroite	-4.79	10.30	15.09	Mn(OH)2
Rhodochrosite	0.12	-10.29	-10.41	MnCO3
Siderite	-0.77	-11.32	-10.55	FeCO3
Thenardite	-6.74	-6.92	-0.18	Na2SO4
Thermonatrite	-10.38	-10.25	0.12	Na2CO3:H2O

Distribution of species

	Species	Molality	Log Activity	Log Molality	Log Activity	Gamma
	OH-	2.116e-07	1.747e-07	-6.675	-6.758	-0.083
	H+	6.665e-08	5.748e-08	-7.176	-7.240	-0.064
	H2O	5.551e+01	9.993e-01	0.000	0.000	0.000
C(4)	1.845e-03	98 mg/L as HCO3				
	HCO3-	1.604e-03	1.348e-03	-2.795	-2.870	-0.076
	H2CO3	1.723e-04	1.739e-04	-3.764	-3.760	0.004
	CaHCO3+	5.048e-05	4.263e-05	-4.297	-4.370	-0.073
	MgHCO3+	5.675e-06	4.708e-06	-5.246	-5.327	-0.081
	CaCO3	4.717e-06	4.760e-06	-5.326	-5.322	0.004
	NaHCO3	4.213e-06	4.252e-06	-5.375	-5.371	0.004
	CO3-2	2.201e-06	1.097e-06	-5.657	-5.960	-0.302
	MnHCO3+	8.744e-07	7.287e-07	-6.058	-6.137	-0.079
	MgCO3	3.083e-07	3.112e-07	-6.511	-6.507	0.004
	NaCO3-	1.357e-07	1.140e-07	-6.867	-6.943	-0.076
Ca	8.322e-03	333 mg/L				
	Ca+2	5.913e-03	3.053e-03	-2.228	-2.515	-0.287
	CaSO4	2.353e-03	2.375e-03	-2.628	-2.624	0.004
	CaHCO3+	5.048e-05	4.263e-05	-4.297	-4.370	-0.073
	CaCO3	4.717e-06	4.760e-06	-5.326	-5.322	0.004
	CaOH+	1.586e-08	1.340e-08	-7.800	-7.873	-0.073
Cl	7.406e-03					
	Cl-	7.405e-03	6.090e-03	-2.130	-2.215	-0.085
	MnCl+	8.537e-07	7.149e-07	-6.069	-6.146	-0.077
	MnCl2	1.172e-09	1.183e-09	-8.931	-8.927	0.004
	MnCl3-	3.877e-12	3.247e-12	-11.411	-11.489	-0.077
	FeCl+2	9.660e-19	4.750e-19	-18.015	-18.323	-0.308
	FeCl2+	1.543e-20	1.292e-20	-19.812	-19.889	-0.077
	FeCl3	7.796e-24	7.869e-24	-23.108	-23.104	0.004
Fe(2)	7.120e-06					
	Fe+2	5.292e-06	2.691e-06	-5.276	-5.570	-0.294
	FeSO4	1.811e-06	1.828e-06	-5.742	-5.738	0.004
	FeOH+	1.767e-08	1.480e-08	-7.753	-7.830	-0.077
	Fe(OH)2	2.169e-12	2.189e-12	-11.664	-11.660	0.004
	Fe(OH)3-	1.689e-15	1.414e-15	-14.772	-14.849	-0.077
	Fe(HS)2	0.000e+00	0.000e+00	-80.694	-80.690	0.004
	Fe(HS)3-	0.000e+00	0.000e+00	-120.609	-120.688	-0.079
Fe(3)	2.395e-09					
	Fe(OH)2+	1.986e-09	1.669e-09	-8.702	-8.777	-0.076
	Fe(OH)3	3.378e-10	3.410e-10	-9.471	-9.467	0.004
	Fe(OH)4-	7.055e-11	5.928e-11	-10.152	-10.227	-0.076
	FeOH+2	5.896e-13	2.900e-13	-12.229	-12.538	-0.308
	FeSO4+	9.798e-17	8.205e-17	-16.009	-16.086	-0.077
	Fe(SO4)2-	1.189e-17	9.908e-18	-16.925	-17.004	-0.079
	Fe+3	9.793e-18	2.583e-18	-17.009	-17.588	-0.579
	FeCl+2	9.660e-19	4.750e-19	-18.015	-18.323	-0.308
	FeCl2+	1.543e-20	1.292e-20	-19.812	-19.889	-0.077
	Fe2(OH)2+4	4.183e-23	2.263e-24	-22.378	-23.645	-1.267
	FeCl3	7.796e-24	7.869e-24	-23.108	-23.104	0.004
	Fe3(OH)4+5	7.527e-29	7.892e-31	-28.123	-30.103	0.979
H(0)	4.341e-20					
	H2	2.171e-20	2.191e-20	-19.663	-19.659	0.004
Mg	7.707e-04					

	Mg+2	5.648e-04	2.972e-04	-3.248	-3.527	-0.279
	MgSO4	1.999e-04	2.018e-04	-3.699	-3.695	0.004
	MgHCO3+	5.675e-06	4.708e-06	-5.246	-5.327	-0.081
	MgCO3	3.083e-07	3.112e-07	-6.511	-6.507	0.004
	MgOH+	1.001e-08	8.486e-09	-8.000	-8.071	-0.072
Mn(2)	7.879e-05					
	Mn+2	5.706e-05	2.902e-05	-4.244	-4.537	-0.294
	MnSO4	1.998e-05	2.017e-05	-4.699	-4.695	0.004
	MnHCO3+	8.744e-07	7.287e-07	-6.058	-6.137	-0.079
	MnCl+	8.537e-07	7.149e-07	-6.069	-6.146	-0.077
	MnOH+	1.549e-08	1.297e-08	-7.810	-7.887	-0.077
	MnCl2	1.172e-09	1.183e-09	-8.931	-8.927	0.004
	MnCl3-	3.877e-12	3.247e-12	-11.411	-11.489	-0.077
	Mn(OH)3-	2.886e-18	2.417e-18	-17.540	-17.617	-0.077
	Mn(NO3)2	0.000e+00	0.000e+00	-85.718	-85.714	0.004
Mn(3)	3.537e-29					
	Mn+3	3.537e-29	9.330e-30	-28.451	-29.030	-0.579
Mn(6)	0.000e+00					
	MnO4-2	0.000e+00	0.000e+00	-60.690	-60.998	-0.308
Mn(7)	0.000e+00					
	MnO4-	0.000e+00	.000e+00	-69.282	-69.368	-0.086
N(-3)	6.066e-03					
	NH4+	5.744e-03	.691e-03	-2.241	-2.329	-0.088
	NH4SO4-	2.756e-04	.308e-04	-3.560	-3.637	-0.077
	NH3	4.608e-05	.651e-05	-4.336	-4.332	0.004
N(3)	1.786e-29					
	NO2-	1.786e-29	.489e-29	-28.748	-28.827	-0.079
N(5)	0.000e+00					
	NO3-	0.000e+00	0.000e+00	-40.803	-40.888	-0.086
	Mn(NO3)2	0.000e+00	0.000e+00	-85.718	-85.714	0.004
Na	6.843e-03					
	Na+	6.711e-03	5.607e-03	-2.173	-2.251	-0.078
	NaSO4-	1.277e-04	1.073e-04	-3.894	-3.969	-0.076
	NaHCO3	4.213e-06	4.252e-06	-5.375	-5.371	0.004
	NaCO3-	1.357e-07	1.140e-07	-6.867	-6.943	-0.076
O(0)	0.000e+00					
	O2	0.000e+00	0.000e+00	-53.066	-53.062	0.004
S(-2)	0.000e+00					
	HS-	0.000e+00	0.000e+00	-41.952	-42.035	-0.083
	H2S	0.000e+00	0.000e+00	-42.338	-42.334	0.004
	S5-2	0.000e+00	0.000e+00	-44.073	-44.389	-0.317
	S4-2	0.000e+00	0.000e+00	-44.307	-44.623	-0.317
	S6-2	0.000e+00	0.000e+00	-44.359	-44.675	-0.317
	S-2	0.000e+00	0.000e+00	-47.404	-47.712	-0.308
	S3-2	0.000e+00	0.000e+00	-47.760	-48.076	-0.317
	S2-2	0.000e+00	0.000e+00	-49.006	-49.322	-0.317
	Fe(HS)2	0.000e+00	0.000e+00	-80.694	-80.690	0.004
	Fe(HS)3-	0.000e+00	0.000e+00	-120.609	-120.688	-0.079
S(6)	1.107e-02	777 mg/L as SO4				
	SO4-2	8.088e-03	3.819e-03	-2.092	-2.418	-0.326
	CaSO4	2.353e-03	2.375e-03	-2.628	-2.624	0.004
	NH4SO4-	2.756e-04	2.308e-04	-3.560	-3.637	-0.077
	MgSO4	1.999e-04	2.018e-04	-3.699	-3.695	0.004
	NaSO4-	1.277e-04	1.073e-04	-3.894	-3.969	-0.076
	MnSO4	1.998e-05	2.017e-05	-4.699	-4.695	0.004
	FeSO4	1.811e-06	1.828e-06	-5.742	-5.738	0.004

HSO4-	2.555e-08	2.130e-08	-7.593	-7.672	-0.079
FeSO4+	9.798e-17	8.205e-17	-16.009	-16.086	-0.077
Fe(SO4)2-	1.189e-17	9.908e-18	-16.925	-17.004	-0.079

Saturation indices

Phase	SI	log IAP	log KT	
Anhydrite	-0.30	-4.93	-4.64	CaSO4
Aragonite	-0.14	-8.47	-8.34	CaCO3
Artinite	-8.13	1.47	9.60	MgCO3:Mg(OH)2:3H2O
Birnessite	-17.15	26.45	43.60	MnO2
Bixbyite	-14.01	36.40	50.40	Mn2O3
Brucite	-5.84	10.95	16.79	Mg(OH)2
Calcite	0.00	-8.47	-8.47	CaCO3
CH4(g)	-46.38	-86.48	-40.10	CH4
CO2(g)	-2.28	-20.44	-18.16	CO2
Dolomite	-0.96	-17.96	-17.00	CaMg(CO3)2
Epsomite	-3.81	-5.95	-2.14	MgSO4:7H2O
Fe(OH)2.7Cl0.3	4.34	14.33	9.99	Fe(OH)2.7Cl0.3
Fe2(SO4)3	-46.01	-16.37	29.64	Fe2(SO4)3
Fe3(OH)8	-3.05	43.24	46.29	Fe3(OH)8
Ferrihydrite	-0.76	17.16	17.92	Fe(OH)3
FeS(ppt)	-36.45	-74.02	-37.57	FeS
Goethite	3.63	17.17	13.53	FeOOH
Greigite	-134.89	-288.50	-153.61	Fe3S4
Gypsum	-0.09	-4.93	-4.85	CaSO4:2H2O
Halite	-6.05	-4.47	1.58	NaCl
Hausmannite	-15.20	46.34	61.54	Mn3O4
Hematite	12.27	34.33	22.06	Fe2O3
Huntite	-6.97	-36.93	-29.97	CaMg3(CO3)4
Hydromagnesite	-18.23	-26.99	-8.77	Mg5(CO3)4(OH)2:4H2O
Jarosite-H	-9.30	17.70	27.00	(H3O)Fe3(SO4)2(OH)6
Jarosite-Na	-5.21	22.69	27.90	NaFe3(SO4)2(OH)6
Lepidocrocite	2.76	17.17	14.40	FeOOH
Lime	-20.83	11.97	32.80	CaO
Mackinawite	-35.72	-74.02	-38.31	FeS
Maghemite	1.88	34.33	32.45	Fe2O3
Magnesite	-1.46	-9.49	-8.03	MgCO3
Magnetite	13.44	43.24	29.80	Fe3O4
Manganite	-7.07	18.20	25.27	MnOOH
Melanterite	-5.52	-7.99	-2.47	FeSO4:7H2O
Mg-Ferrite	2.45	45.28	42.83	MgFe2O4
Mirabilite	-5.81	-6.92	-1.11	Na2SO4:10H2O
Mn2(SO4)3	-59.60	-14.30	45.30	Mn2(SO4)3
MnCl2:4H2O	-11.68	-8.97	2.71	MnCl2:4H2O
MnS(Green)	-43.13	-72.99	-29.86	MnS
MnSO4	-9.62	-6.96	2.67	MnSO4
Natron	-9.15	-10.47	-1.31	Na2CO3:10H2O
Nesquehonite	-3.87	-9.49	-5.62	MgCO3:3H2O
Nsutite	-16.56	26.45	43.01	MnO2
O2(g)	-50.10	33.02	83.12	O2
Periclase	-10.56	10.95	21.51	MgO
Portlandite	-10.71	11.97	22.68	Ca(OH)2
Pyrite	-54.65	-140.45	-85.80	FeS2
Pyrocroite	-5.14	9.94	15.09	Mn(OH)2
Pyrolusite	-14.92	26.45	41.37	MnO2

Rhodochrosite	-0.09	-10.50	-10.41 MnCO3
Siderite	-0.98	-11.53	-10.55 FeCO3
SULFUR	-30.66	-66.43	-35.77 S
Thenardite	-6.74	-6.92	-0.18 Na2SO4
Thermonatrite	-10.59	-10.46	0.12 Na2CO3:H2O